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ABSTRACT

This module is the tenth of 10 modules in the competency-based electronics series. Introductory materials include a listing of competencies addressed in the module, a parts/equipment list, and a cross-reference table of instructional materials. Six instructional units cover: electromechanical control devices; programmable logic controllers (PLC); stepper motors; digital control systems; motor speed control; and analog electronic control devices. Each unit includes some or all of the following components: performance objectives; information sheets; transparency masters; handouts; assignment sheets; job sheets; and unit test with answer key. Special instructions are included in the notes to the instructor section near the beginning of each unit. (YLB)

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ED 256680

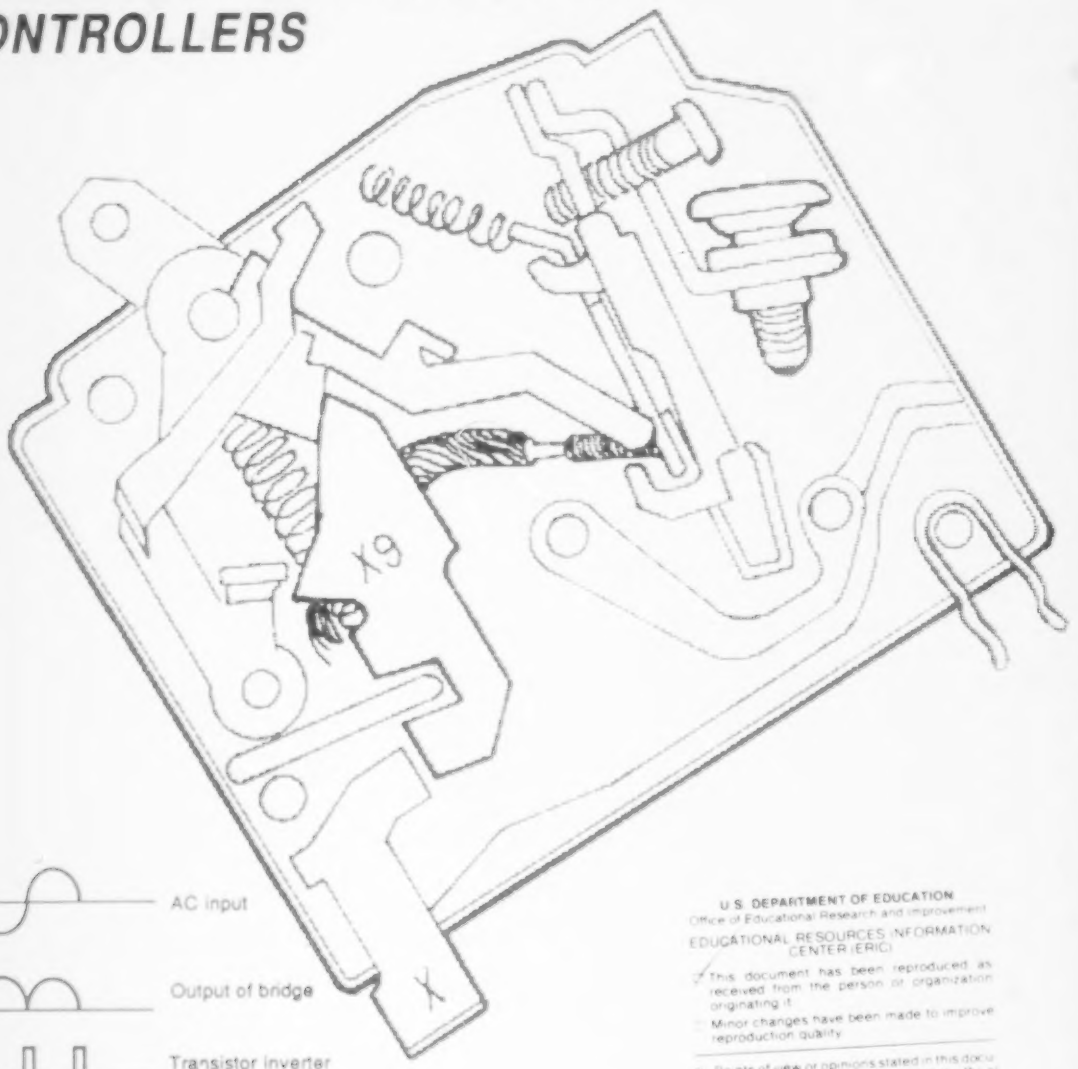
ELECTRONICS

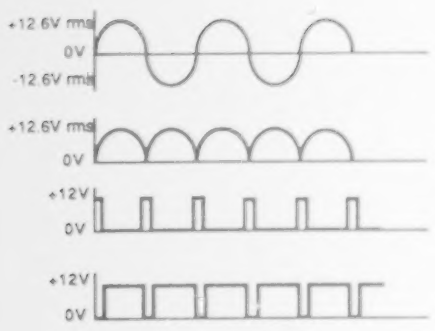
Module

10

70-5010-1
Instructor's Guide

ELECTROMECHANICAL DEVICES AND CONTROLLERS





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Modules in this IML Electronics series

1: *Electronic Safety* by Bill Tharp
2: *Fundamentals of Electronics* by Jim Everett
3: *Digital Logic Application* by Ed Carter and Mark Murphy
4: *Circuit Construction Techniques* by Don Slack
5: *Semiconductor Devices and Applications* by John Chappell, Bill Franken and Mark Murphy
6: *Receivers and Transmitters* by Jim Everett
7: *Testing and Troubleshooting* by Don Slack
8: *Microprocessor and Computer Systems* by Don Slack
9: *Optical Electronics* by Bill Franken
10: *Electromechanical Devices and Controllers* by Ed Carter

The activity which is the subject of this report was supported in whole or in part by funds from the Department of Elementary and Secondary Education, Division of Vocational and Adult Education. However, the opinions expressed herein do not necessarily reflect the position or policies of the Missouri Department of Elementary and Secondary Education or the Division of Vocational and Adult Education, and no official endorsement should be inferred.

ELECTRONICS

Module 10: Electromechanical Devices and Controllers

by

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1990

Instructor's Guide
Catalog No. 70-5010-I

FOREWORD

Once again, we are indebted to the teachers and administrators who provide their time, efforts and professionalism to develop curriculum for trade, technical and industrial education programs. This electronics guide is an outstanding example of what can be accomplished when the right people with the right attitude get together. Committee members worked hard over several years' time in advisory, writing, technical consultation and field-test capacities.

This guide is designed to be totally integrated with the Vocational Instructional Management System. It is hoped that all guides produced under our supervision will help classroom teachers manage instruction. A curriculum guide is more than a resource--it is an integral part of the management system. Rather than impeding instruction, it should guide and facilitate instruction.

This guide's format has been set up for competency-based teaching and testing. Unit tests evaluate specific competencies and can be used with the Vocational Administrative Management System (VAMS). Information sheets, transparency masters, job sheets, assignment sheets and test items are keyed to specific competencies. A cross-reference table has been included to quickly identify parts of the curriculum that relate to specific competencies. The material has also been packaged for students.

Although this guide may be a new format for some teachers, we are confident that, when used as designed, time spent by teachers and students will become more productive. Any future electronics curriculum modifications will begin with this guide. The electronics field is undergoing constant and considerable change. We will annually evaluate the need to update this guide on a module-by-module basis. Your suggestions regarding areas for improvement are both encouraged and appreciated.

Judith Moore, supervisor
Industrial Education
Department of Elementary and Secondary Education

Charles "Chuck" Waibel, director
Industrial Education
Department of Elementary and Secondary Education

ACKNOWLEDGMENTS

This electronics guide represents a continuing commitment to Missouri's Vocational Instructional Management System (VIMS). The guide has been keyed to the electronics competency profile developed by industry and education professionals in the state.

When searching for current electronics materials to adopt or utilize in the guide's development, comparable materials were found from the Mid-America Vocational Curriculum Consortium (MAVCC), of which Missouri is a member. MAVCC materials, therefore, have been relied upon as a resource for this guide. A debt of thanks is owed to the entire MAVCC organization for the research and development of these electronics materials.

Special appreciation is given to the writers (Ed Carter, John Chappell, Jim Everett, Bill Franken, Mark Murphy, Don Slack and Bill Tharp) for their self-motivation, reliability and technical expertise. IML employees Crystal Dietiker and Donna Curtis contributed greatly to the guide's production.

These industry representatives and educators contributed to the guide as members of the advisory committee.

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Support and contributions of IML staff members were instrumental to this module's development.

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Hsiu-Nien (Shelley) Chen, student assistant - technical
Donna Curtis and Lori Holliday, word processors
Mary Beth Ramsey, student assistant - clerical

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Unit VI: Analog Electronic Control Devices 107

COMPETENCIES ADDRESSED IN THIS MODULE

L. Electromechanical Devices and Controllers

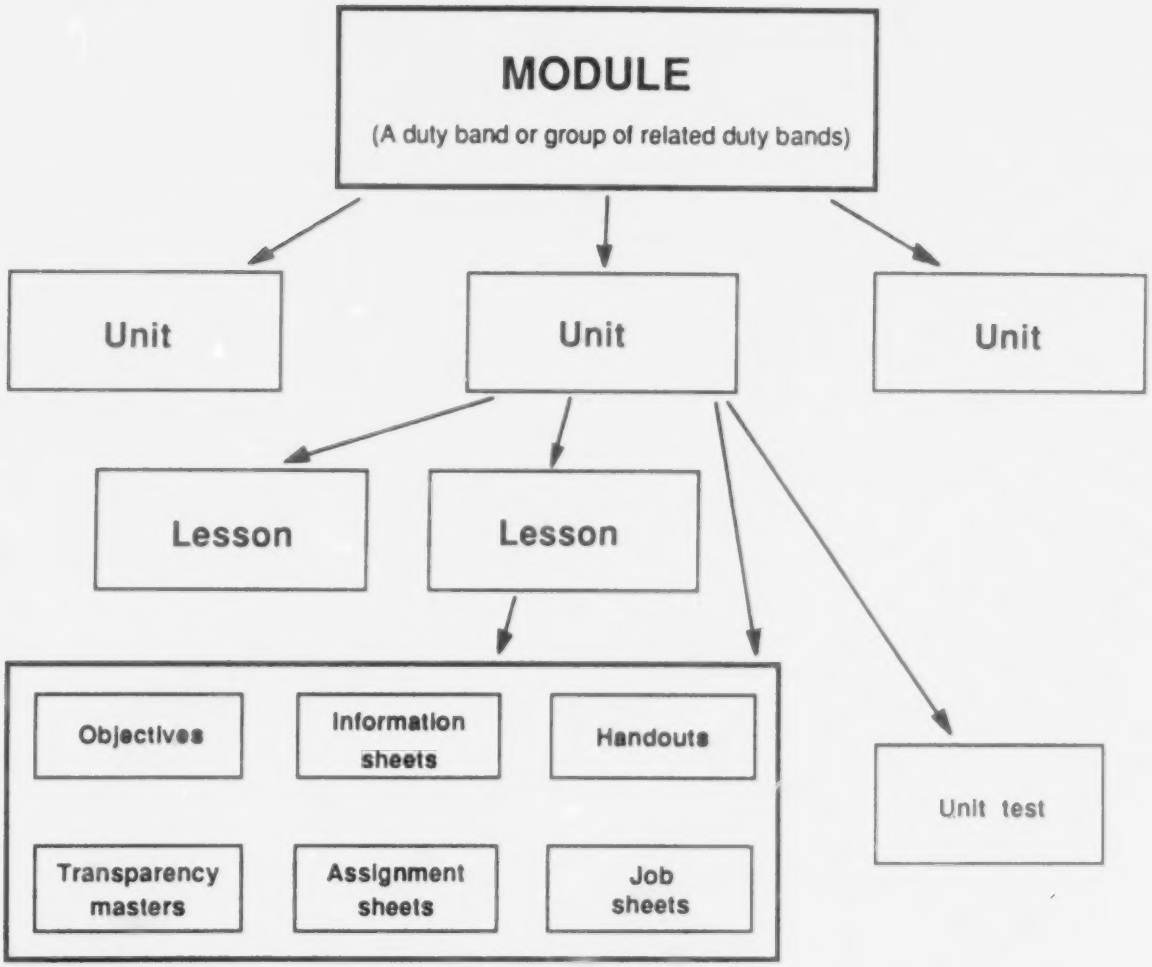
3. Test and repair a stepper motor
4. Test and repair electromechanical control devices
5. Test and repair analog electronic control devices
6. Test and repair digital electronic control devices
7. Explain the proper connection of delta and wye motor connections
8. Describe the operation of motor speed control
9. Describe the operation of programmable controllers

HOW TO USE THIS PUBLICATION

GUIDE COMPONENTS

Units of instruction

This Electronics guide contains ten modules of instruction. Within each module are instructional units including some or all of the following components: performance objectives, information sheets, transparency masters, handouts, assignment sheets, job sheets and a unit test. Special instructions on audiovisuals, supplies, etc. are included in the Notes to the Instructor section near the beginning of each unit.



Competency profile

On the Missouri competency profile, tasks are divided into general subject areas, or duty bands, which are identified by a capital letter. Under each duty band are related tasks (competencies), which are identified by an Arabic numeral. To evaluate the student on performance of the competencies, a 3-2-1-N grading system is used, where:

- 3 = **Mastery** - can work independently with no supervision
- 2 = **Requires supervision** - can perform job completely with limited supervision
- 1 = **Not mastered** - requires instruction and close supervision
- N = **No exposure** - no experience or knowledge in this area

Cross-reference table (color-coded white)

Once the numbering system is understood, this table quickly reveals how the instructional components of the module relate to Missouri competencies. On the competency profile, tasks are divided into general subject areas, or duty bands, which are identified by a capital letter. Under each duty band are related tasks (competencies), which are identified by an Arabic numeral.

On the cross-reference table, unit numbers are represented by Roman numerals (I, II, III, etc.). Lessons within a unit are shown with Arabic numerals. Therefore, the first objective in Lesson 1 is numbered 1.1, the second is 1.2, and so on. Other components of the module (transparencies, handouts, assignment sheets and job sheets) also use this numbering system. By looking at the cross-reference table, the instructor can quickly determine what test questions or job sheets a student needs to receive an evaluation on a particular competency.

Objectives (color-coded white)

Each unit is based on performance objectives which state the measurable unit and specific behavioral or performance objectives that students are expected to achieve. Since the objectives of the unit provide direction for the teaching-learning process, it is important for the teacher and students to have a common understanding of the objectives' intent. Teachers should feel free to add/adapt objectives which will fit the material to student and community needs. Supporting material will, of course, need to be added for any new objectives.

Table of contents, references, notes to the instructor (color-coded pink)

These pages have been coded pink for instructor use only. The reference section lists materials used as sources in developing the material. Special instructions on audiovisuals, supplies, etc. are included in the Notes to the Instructor section.

Information sheets (green)

Presented in outline form for clarity, these pages provide content essential for meeting the cognitive (knowledge) objectives in the unit. Students should study the information sheets before class discussion or completion of assignment sheets. **CAUTION** statements indicate possible equipment damage, while **WARNING** statements recommend procedures to avoid bodily injury. Handouts and transparency masters have been keyed in the information sheets for instructional use.

Transparency masters (white)

Transparencies provide information by visually reinforcing or clarifying ideas presented in the information sheets. They are effective when identification is necessary and direct the class's attention to the topic of discussion. Transparencies should be left on the screen only when topics shown are under discussion, however.

Handouts (white)

Whenever more detailed information than can be presented in a transparency is needed, a handout is used. Handouts give the students additional information that can be kept with their class notes or student references.

Assignment sheets (tan)

Assignment sheets furnish paper-and-pencil practice to develop the knowledge necessary as a prerequisite to skill development. They can be given to students for class completion or used as homework assignments. Answer sheets (color-coded pink) can be used by the student or instructor to check progress.

Job sheets (blue)

These evaluation instruments are provided for two purposes: to outline steps of procedure and to check student performance mastery. Job sheets begin with a list of tools and materials needed for the activity. Job sheets furnish potential employers with a picture of skills being taught and performance which might

be reasonably expected from a vocational student. The spaces to the right of the page on a job sheet assist the instructor in evaluating a student on a particular activity. This 3-2-1-N grading system is the same as the one used on the competency profile.

Unit test (yellow)

Competency-based tests are designed to help eliminate subjective testing and to improve student evaluation and accountability. Specific competencies and test questions are linked on the answer key. These unit tests have been written to be used with computerized VAMS (Vocational Administrative Management System), utilizing Scantron sheets for computer-recording of test answers.

The unit test may be eliminated if the competency was thoroughly evaluated by job sheets. However, an emphasis should be placed on cognitive as well as performance skills. If the objective or competency will be evaluated by a job sheet, it is often necessary to determine by a written test whether the student understands enough of the material to perform the job sheet.

SUGGESTED ACTIVITIES

The following list of suggested activities may be helpful, especially to the beginning instructor.

1. Provide students with objective sheet and information sheets.
2. Discuss unit and specific objectives.
3. Discuss information sheets, assignment sheets and/or job sheets, lesson-by-lesson.
4. Have students do assignment sheet(s) to satisfactory levels.
5. Give students unit test.
6. After successful completion of the test, have students do job sheet(s).

Students should perform the following activities.

1. Read objective sheet.
2. Study information sheets.
3. Do assignment sheet(s).
4. Take unit test.
5. Do job sheets.

PACKAGING

This Electronics guide has been packaged with the entire class in mind. For the teacher, a complete instructor's guide contains all ten modules. In the student reference, selected portions have been reproduced for student use (objectives page, information sheets, handouts). Student work sheets (assignment sheets, job sheets, unit tests) have been packaged together for student distribution as the instructor deems necessary.

In the student reference, page numbers do not run consecutively because some pages have been removed that appear only in the instructor's guide.

MODULE 10: ELECTROMECHANICAL DEVICES AND CONTROLLERS

CROSS-REFERENCE TABLE OF INSTRUCTIONAL MATERIALS

Competency	Instructional Objective	Transparency Master	Handout	Assignment Sheet	Job Sheet	Test Item	Notes
L1-2							Not addressed (committee decision)
L3	III 1.1-2.4				III 2.1	III 1-11	
L4	I 1.1-2.4	I 1.1-1.3		I 1.1	I 2.1-2.2	I 1-11	
L5	VI 1.1-1.4				VI 1.1	VI 1-10	
L6	IV 1.1-1.3				IV 1.1	IV 1-10	
L7							I-Notes to instructor
L8	V 1.1-2.2				V 2.1	V 1-7	
L9	II 1.1-2.3					II 1-19	

PARTS/EQUIPMENT LIST

Capacitor, 2.2μF
Capacitor, 0.1μF
Capacitor, 0.01μF (2)
Capacitor, 0.1μF, 200V
DC motor, 5V DC
DC four-phase stepping motor
DC power supplies, 5V and 12V
DC relay, 5V DC, SPDT
DC relay, 12V DC (provided oy instructor)
Diode, 1N914 (2)
Diode, 1N4001 (4)
DVM
Encoder disk
Four-position DIP switch (2)
I.C.s: 74121, 741 op amp, 555
I.C.s: CD40102, 74C14, MOC3030
Incandescent lamp, 60W
Infrared light-emitting diode
Infrared sensitive photo-transistor
Light bulb, 60W
Logic switches (4)
Motor, 6-12V
Multimeter
Neon lamp, NE-2
Oscilloscope
Oscilloscope
PBNC switch
PBNO switch
Potentiometer, 5K
Potentiometer, 10KΩ
Power supply, 12V, 1A
Power supply, 12V DC
Resistor, 50Ω, 1/2 watt
Resistors: 1KΩ, 470Ω, 270Ω, 100KΩ variable
Resistors: 39Ω, 180Ω, 220Ω, 1KΩ (3), 4.7KΩ, 10KΩ, 100KΩ (8)
Resistors: 220Ω, 330Ω, 2.2KΩ (2), 37KΩ, 470KΩ
SCR (GE C106B1 or equivalent)
Silicon diode (4)
Small motor as might be used in 1/4-inch drill
Solderless circuit board
Solderless breadboard
Transformer, 117/12.6V AC, 1A
Transistor, 2N3055 (2)
Transistors: 2N2222 NPN, 2N3906 PNP
TRIAC
Variable DC power supply, 0-12V DC
Zener diode, 5.1V

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT I: ELECTROMECHANICAL CONTROL DEVICES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to identify the parts of circuit breakers, solenoids and relays. The student should be able to test relays and construct circuits using them. This knowledge will be evidenced by achieving the specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify appropriate terms and definitions.

1.2 Identify general types of circuit breakers.

1.3 Differentiate between the operation of automatic and magnetic circuit breakers.

2.1 Define terms and definitions.

2.2 Explain the operation and uses of relays and/or solenoids.

2.3 Test the drop-in and drop-out voltages of a relay. (JS 2.1)

2.4 Construct and test a relay control circuit. (competency L4, JS 2.2)

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT I: ELECTROMECHANICAL CONTROL DEVICES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: CIRCUIT BREAKERS

   a. Information outline

   b. Transparencies

      TM 1.1: Common types of circuit breakers
      TM 1.2: Circuit breaker construction
      TM 1.3: Magnetic circuit breaker construction

   c. Assignment sheet

      AS 1.1: Electromechanical control devices

   d. Answers to assignment sheet

2. Lesson 2: RELAYS AND SOLENOIDS

   a. Information outline

   b. Job sheets

      JS 2.1: Measure relay drop-in and drop-out voltages
      JS 2.2: Construct and test a lock-out relay circuit

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Gerrish, Howard H. Transistor Electronics. San Jose, CA: Goodheart-Willcox Co., Inc., 1969.

2. Schuler, Charles A.; Richard J. Fowler. Basic Electricity and Electronics. St. Louis: McGraw-Hill, 1988.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Mention the importance of NEC (National Electrical Code) and UL (Underwriters' Laboratories) standards.

B. Suggested supplemental materials

1. For the instructor who wishes to cover multiphase voltage such as delta and wye motor connection controls **(competency L7)**, incorporate the following material as applicable in your class.

Power in three-phase circuits

Delta--Voltage across each load member is the full-line voltage. Amperage in each member is $\sqrt{3}$ x line amps or 1.732 x amps.

Wye--Amperage in each member is full-line amperage. Voltage across each member is $\sqrt{3}$ x line volts or 1.732 x line volts.

NOTE: To find the power in delta or wye circuits, use the formula $P = I \times \sqrt{3} \times E$.

Example: A three-phase circuit has 10A measured on each line. The voltage is 480V. It is not known whether the circuit is delta or wye. What is the power of the circuit?

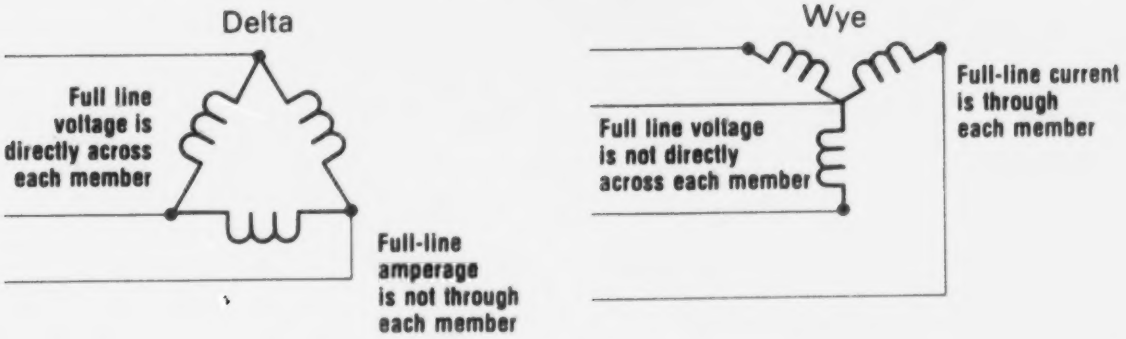
Solution: $P = I \times \sqrt{3} \times E$
$= 10 \times 480 \times 1.732$
$= 8{,}314$ VA
$= 8.3$ KVA

Steps for identifying three-phase transformer connections

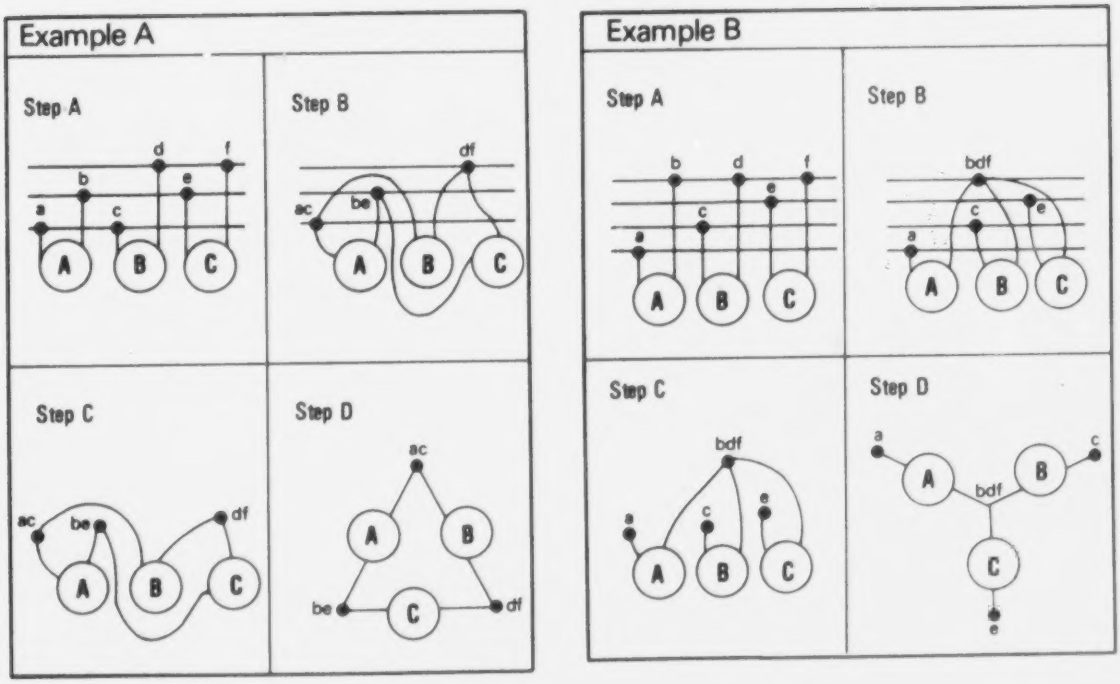
Label circuit components and connection points.

Redo the circuit sketch so that connections along the same wire are all at one point, looping wires as necessary and avoiding crossing wires as much as possible.

Three-Phase Voltage, Current, and Power


Delta
Full line voltage is directly across each member
Full-line amperage is not through each member
Wye
Full line voltage is not directly across each member
Full-line current is through each member

Procedure for Identifying Three-Phase Connections



MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT I: ELECTROMECHANICAL CONTROL DEVICES

LESSON 1: CIRCUIT BREAKERS

I. Terms and definitions

A. Bimetallic--a two-metal structure that bends when heated or cooled due to expansion coefficients

B. Circuit breaker--an overcurrent device that can be reset after it performs its function

C. Tripped--an open circuit breaker

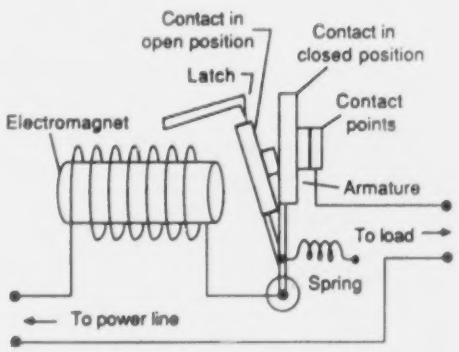
II. General types and operation **(TM 1.1, 1.2)**

A. Circuit breakers are used to protect electric devices against excessive current. Circuit breakers have the advantage of opening a circuit by "tripping". A tripped circuit breaker can be reset by pushing a button or resetting a switch.

B. TM 1.1 shows common types of circuit breakers.

C. Another type of circuit breaker automatically resets itself after cooling down from excessive current flow.

D. Current flows through a bimetallic strip during normal operation. Bimetallic strips are made up of two different types of metal alloy, each having a different expansion coefficient.



Basic construction

1. As metal heats, its physical dimensions expand. The metal that makes up the bottom bimetallic strip has a greater expansion coefficient. It increases its length dependent upon the amount of current flowing.

2. As current increases, the bimetallic strip lengthens, bending upward, opening the spring-controlled lever and breaking the contact.

3. The spring-controlled lever is constructed so that it will hold and prevent the bimetallic strip from closing the contact after it cools down.

4. A reset switch or button must be manually pushed to move the hold lever. Once the hold lever is pushed, the bimetallic strip returns to its normal position, closing the contacts and permitting current to flow to a device.

E. There are four ratings associated with circuit breakers that must be considered when selecting a circuit breaker.

1. The first is the **current** value at which the circuit breaker will disconnect the circuit from the supply and the current value at which the circuit breaker can operate without damage to the equipment.

2. **Voltage** rating is another important consideration. The circuit breaker should be rated at a voltage equal to or greater than the system voltage.

3. The **frequency** of the system must be considered and matched to the circuit breaker.

4. The **ambient temperature** and temperature build-up caused by current is very important.

NOTE: The circuit breaker's location should also be considered.

III. Automatic vs. magnetic circuit breakers **(TM 1.3)**

A. Automatic

1. Another type of circuit breaker resets itself automatically after cooling down from excessive current.

2. If the hold lever is eliminated from the reset circuit breaker, the circuit breaker will automatically reset after it cools down.

B. Magnetic

1. The magnetic circuit breaker also protects circuits and equipment from excessive current.

2. TM 1.3 shows magnetic circuit breaker construction.

3. The magnetic circuit breaker consists of an electromagnet and two contact points connected in series with one wire of a circuit.

4. When the current is more than the ampere rating of the circuit breaker, the electromagnet becomes strong enough to attract the armature.

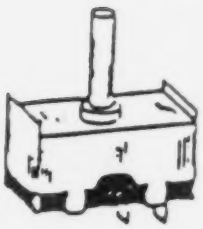
5. The armature moves and latches the contact point in the open position, breaking the circuit. This type of circuit breaker has to be manually reset.

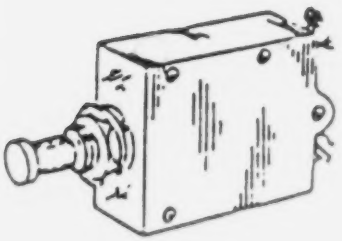
6. Magnetic circuit breakers react quickly. Their fast tripping action is an advantage for protecting against damage caused by short circuits.

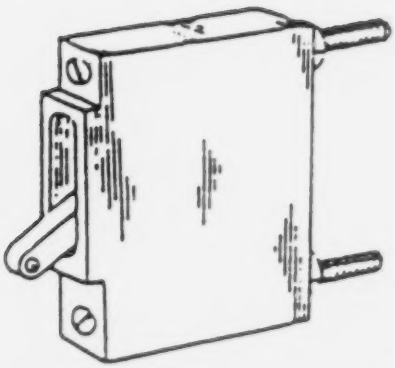
7. Thermal breakers take more time to trip and offer an advantage for protecting circuits where current surges are normal.

8. Some circuit breakers use both thermal and magnetic principles to provide time-delay tripping for moderate overloads and very fast tripping for severe overloads.

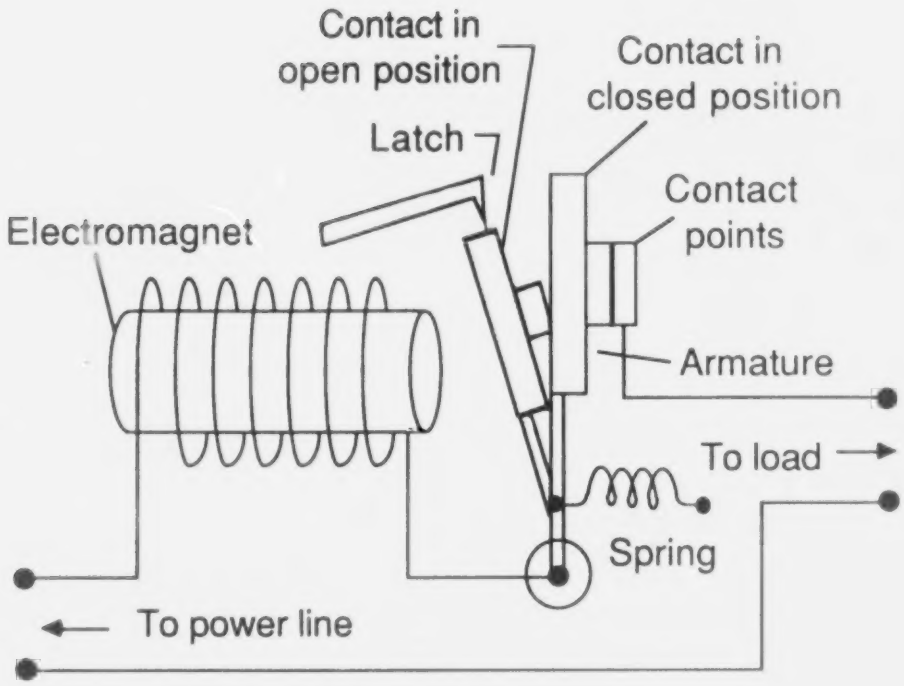
COMMON TYPES OF CIRCUIT BREAKERS



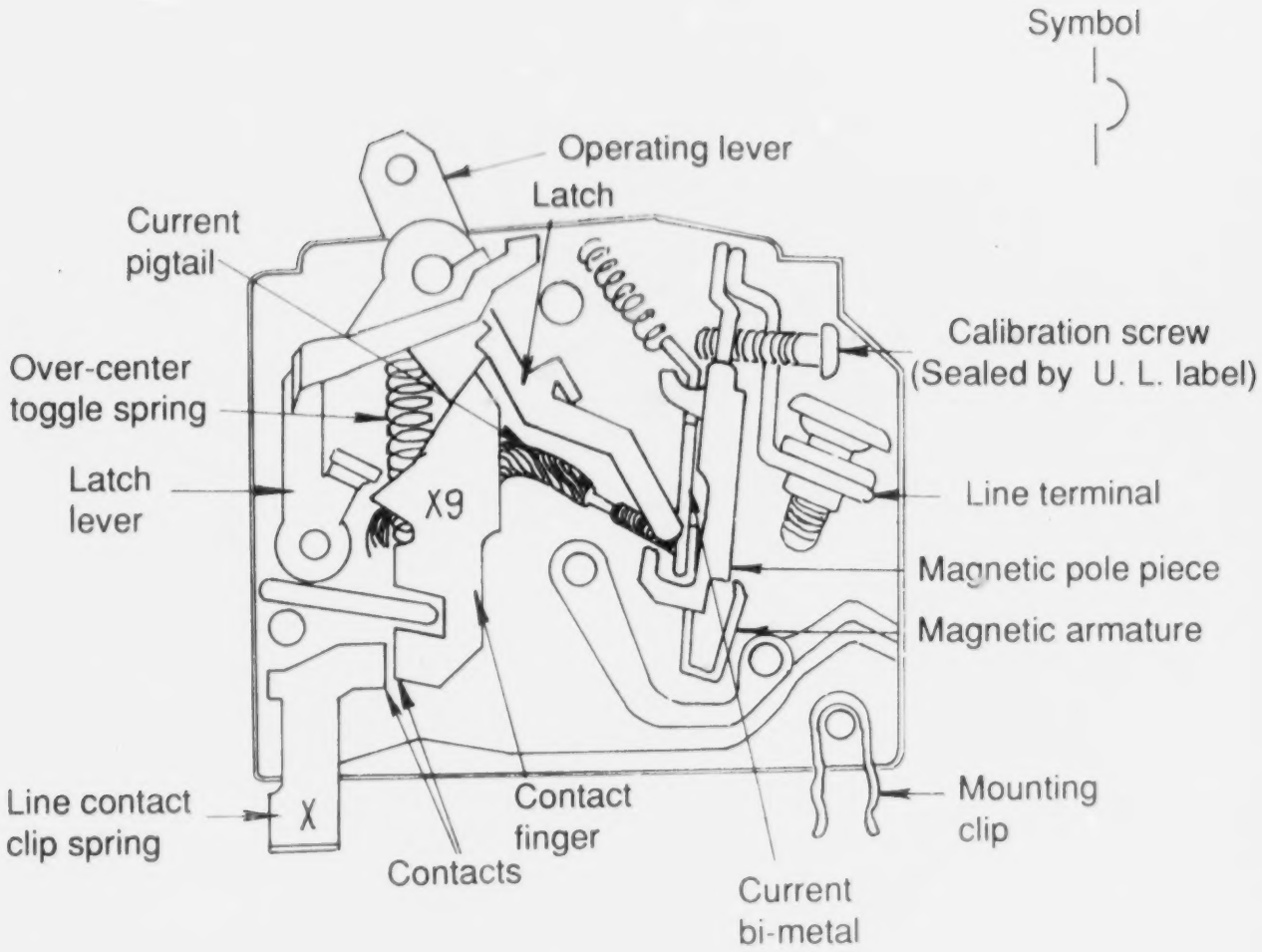




CIRCUIT BREAKER CONSTRUCTION



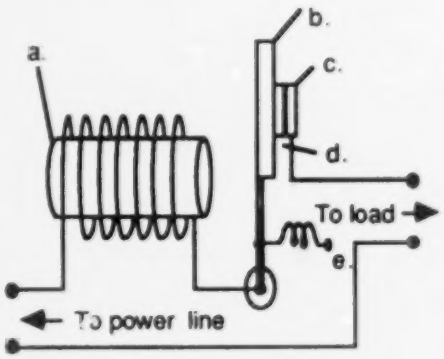
MAGNETIC CIRCUIT BREAKER CONSTRUCTION



ELECTROMECHANICAL CONTROL DEVICES

Select the appropriate response.

1. Magnetic circuit breakers react to overloads in (more / less) time than thermal circuit breakers.
2. Thermal circuit breakers use a (bimetallic / mechanical) strip to open the circuit.
3. Circuit breakers can be manually reset or (remotely / automatically) reset.
4. A circuit breaker that is tripped is said to be (on / off).
5. Is the contact of the circuit breaker shown in the open or closed position? _____
6. Which part is the electromagnet? _____
7. Which part is the armature? _____



ANSWERS TO AS 1.1

1. Less
2. Bimetallic
3. Automatically
4. Off
5. Closed
6. a
7. d

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT I: ELECTROMECHANICAL CONTROL DEVICES

LESSON 2: RELAYS AND SOLENOIDS

I. Terms and definitions

A. Armature--moving part of a relay

B. Deenergized--when current is not sufficient to keep a relay energized

C. Drop-out voltage--amount of voltage when a relay deenergizes

D. Energized--when current is sufficient to operate a relay's coil

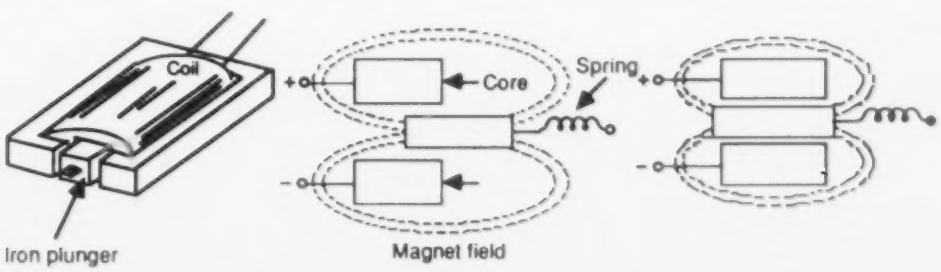
E. Pull-in voltage--amount of voltage required to energize a relay

F. Relay--magnetic switch

G. Solenoid--coil of wire carrying an electric current which acts as a magnet

II. Solenoids

A. A typical solenoid is shown below. A solenoid is a coil with an iron core and a movable iron plunger. The movable plunger is placed in the hollow center of a solenoid.



Typical solenoid

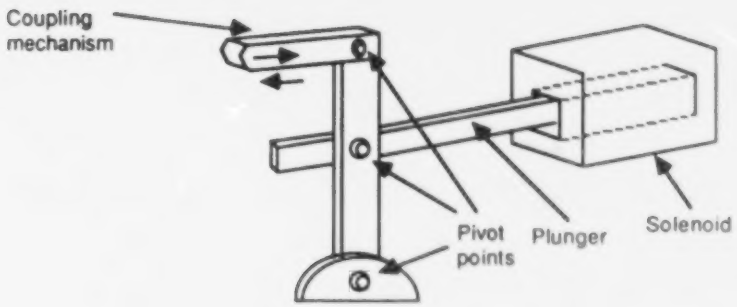
B. When the coil is energized a magnetic field appears, as illustrated in the center part of the above illustration. This magnetic field attracts the iron plunger and pulls it into the center of the coil.

C. The pull-in of the plunger can be used to activate another mechanism (see artwork).

D. The automobile industry also uses solenoids in the starters of some automobiles. Solenoids are used to mesh the pinion gear on the starter with the flywheel.

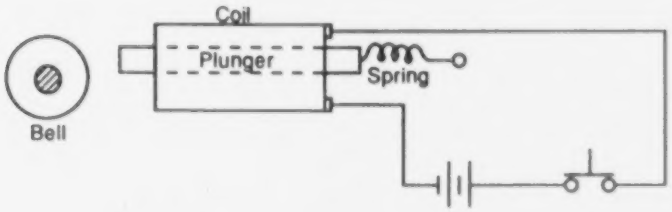
E. The advantage is that the high current needed to activate the starter does not have to flow through the ignition switch.

F. Solenoids are used in homes in dishwashers and washing machines to turn the hot and cold water on and off and to change cycles of operation.



Plunger activation

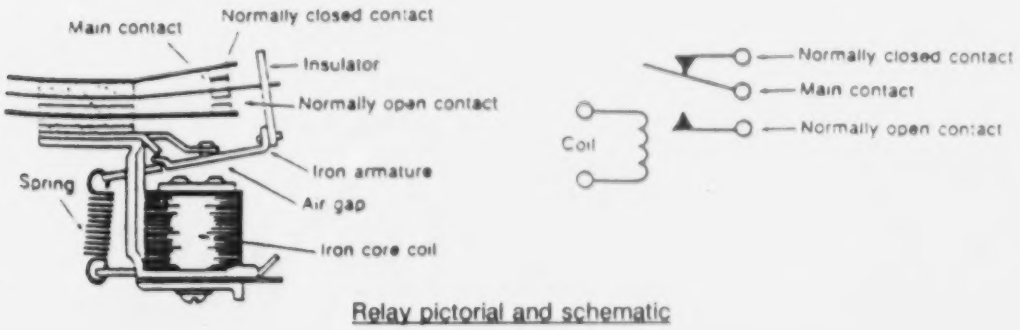
G. Another use of the solenoid, a door chime, is shown below. When the push button is closed, the plunger is attracted through the coil, striking the chime.



Solenoid as a doorbell

III. Relays

A. A relay is a magnetic switch. The left illustration below shows the pictorial diagram of a relay, and the right drawing shows the schematic symbol for a relay.



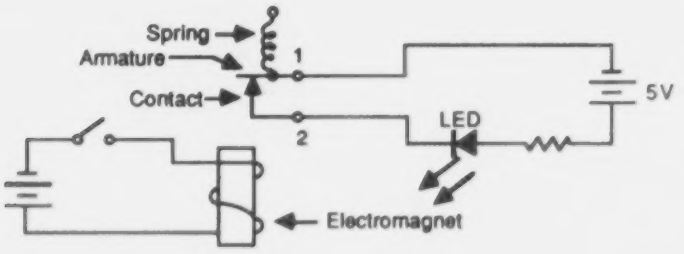
Relay pictorial and schematic

B. A movable spring armature is mounted above the core of an electromagnet. When the coil is energized, the armature is attracted.

C. Contact points then open or close, depending upon the relay's configuration. A relay in a normally closed position and which opens when energized is specified as N.C. A normally open relay (N.O.) closes when energized.

D. When the energizing voltage is removed, the spring action returns the armature to its normal state.

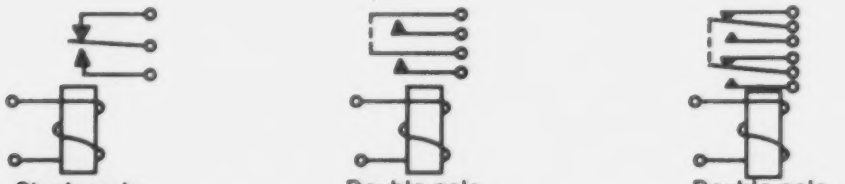
E. Shown below is the basic operation of a single-pole-single-throw relay.



SPST relay

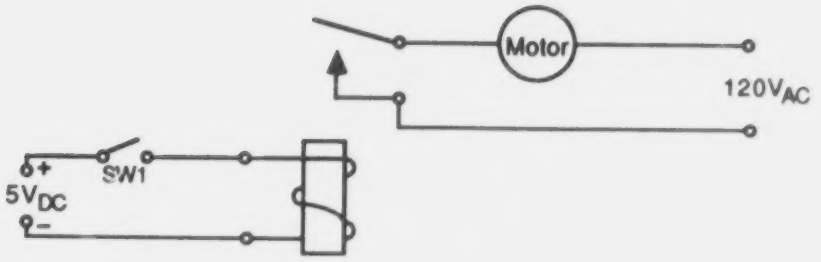
F. When the switch in the circuit is closed, the electromagnet is energized. The armature is attracted to the fixed contact point. With continuity between terminals 1 and 2, the LED is turned on.

G. When the switch is opened, current ceases to flow through the coil. The relay becomes deenergized, which permits the spring to pull the armature to its normal position. This action breaks the connection between terminals 1 and 2, turning the LED off.



Typical relay arrangements

H. One important use of a relay is its ability to control a large load current at a high voltage by using a small energizing voltage. An example of this follows.



1. The relay coil is energized by a 5V source. Thus, the current in the control circuit will be small.

2. The motor is operated from another source of energy, 120V AC. Current in the controlled circuit can be quite large.

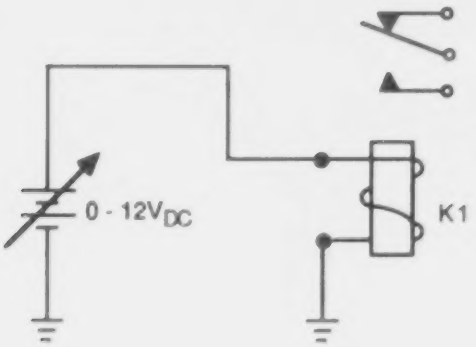
I. Most relays are rated in terms of (1) the operating voltage of the relay coil and whether it is to be operated with AC or DC voltage, (2) the resistance of the coil and (3) the current rating of the contacts. This indicates the safe load current a relay can control.

MEASURE RELAY DROP-IN AND DROP-OUT VOLTAGES

Equipment:

DC relay, 12V DC (provided by instructor)
Multimeter
Variable DC power supply, 0-12V DC

NOTE: Relays usually have the operating voltages identified somewhere on the relay. There are relays that operate on DC and AC voltages. To test a relay under normal operating conditions, it is necessary to determine the minimum voltage (drop-in) that a relay must have to become energized and the voltage at which a relay becomes deenergized (drop-out). In this job sheet, determine the drop-in and drop-out voltages of a relay.



Procedure:		Evaluation 3	2	1	N
1.	Connect the above circuit with the power supply off.	—	—	—	—
2.	Identify the normally open (N.O.) contacts using an ohmmeter.	—	—	—	—
3.	Identify the normally closed (N.C.) contacts using an ohmmeter.	—	—	—	—
4.	Connect an ohmmeter across the normally open contacts.	—	—	—	—
5.	From 0V, gradually increase the power supply voltage until you hear a click (armature and contact closure) and the ohmmeter reads 0Ω.	—	—	—	—
6.	Measure the DC voltage applied to the relay. List this voltage (drop-in voltage). _____V	—	—	—	—
7.	Connect the ohmmeter across the normally closed contacts of the relay. It should measure open if the relay is still energized.	—	—	—	—
8.	Gradually decrease the applied voltage until you hear the relay click or the ohmmeter indicates 0Ω.	—	—	—	—
9.	Measure the applied voltage (drop-out) voltage. _____V	—	—	—	—

10. As directed by instructor, prepare for next job sheet or return tools and materials. ___ ___ ___ ___

Average of above evaluations* ___ ___ ___ ___

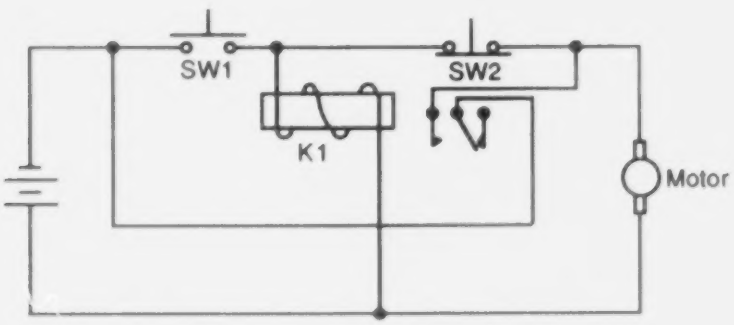
*This average is the student's partial evaluation for competency L4: Test and repair electromechanical control devices.

CONSTRUCT AND TEST A LOCK-OUT RELAY CIRCUIT

Equipment:

DC relay, 5V DC, SPDT
DC motor, 5V DC
PBNC switch
PBNO switch

NOTE: On some large shop machines, the operator has to use a switch (normally green) to start a machine and another switch (normally red) to stop the machine. This job sheet requires the construction of this circuit so that once S1 is pressed, the motor will start and remain running. Only S2 can stop the motor.



Procedure:	Evaluation 3	2	1	N
1. Construct the circuit above.	—	—	—	—
2. Apply 5V DC to the circuit.	—	—	—	—
3. Press S1; the motor should start and continue to run after S1 is released.	—	—	—	—
4. Once the motor is running and S1 operates properly, press S2. The motor should stop.	—	—	—	—
5. Return all parts to the instructor.	—	—	—	—
Average of above evaluations*	—	—	—	—

*This completes the student's evaluation for competency L4: Test and repair electromechanical control devices.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT I: ELECTROMECHANICAL CONTROL DEVICES

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which device is used to protect electrical devices from excess current and can be reset after excess current?

a. Relay
b. Fuse
c. Circuit breaker
d. Solenoid
e. Electromagnet

____ 2. What does "tripped" refer to?

a. Open circuit breaker
b. Closed circuit breaker
c. Normally open relay contact
d. Normally closed relay contact
e. None of the above

____ 3. Which is the fastest-acting circuit breaker?

a. Thermal
b. Bimetallic
c. Automatic
d. Magnetic
e. Fuse

____ 4. What kind of strip do thermal circuit breakers use to open the circuit?

a. Bimetallic
b. Magnetic
c. Mechanical
d. Glass
e. Plastic

____ 5. In reference to a relay, what does "deenergized" mean?

a. Current is not sufficient to keep the relay energized
b. Current is sufficient to close the contacts of a relay
c. Voltage is insufficient
d. Operational relay
e. Defective relay

____ 6. What is the purpose of pull-in voltage?

a. Deactivate the relay
b. Energize the relay
c. Cause the relay not to operate
d. Maximum voltage the relay can accept
e. None of the above

___ 7. Which describes a relay?

a. Open switch
b. Closed switch
c. DPDT switch
d. Magnetic switch
e. SPDT switch

___ 8. Which describes the part of a relay that moves when a magnetizing force is applied?

a. Normally open contact
b. Normally closed contact
c. Armature
d. Coil
e. Electromagnet

___ 9. Which describes the movable part of a solenoid?

a. Coil
b. Plunger
c. Normally open contact
d. Normally closed contact
e. Electromagnet

___ 10. What is one important relay use?

a. Control large load current and voltage with small energizing voltage
b. Control small current and voltage using a high energizing voltage
c. Replace small switches used to turn on appliances
d. Replace circuit breakers
e. None of the above

___ 11. Which is <u>not</u> a rating associated with circuit breakers?

a. Disconnect and operating current
b. Voltage
c. Frequency of the system
d. Ambient temperature and temperature build-up
e. Electromagnet strength

ANSWERS TO UNIT TEST (L4)

1. c
2. a
3. d
4. a
5. a
6. b
7. d
8. c
9. b
10. a
11. e

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT II: PROGRAMMABLE LOGIC CONTROLLERS (PLC)

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to name the basic parts of a PLC, identify electrical symbols and understand how a basic ladder diagram is constructed.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify PLC terms and definitions.

1.2 Identify the main components of a PLC system.

1.3 Identify the symbols used in ladder diagrams.

2.1 State the rules used in developing a ladder diagram.

2.2 Describe sequencing of a ladder diagram.

2.3 Develop a basic ladder diagram for an event sequence. (competency L9)

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT II: PROGRAMMABLE LOGIC CONTROLLERS (PLC)

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the Instructor

D. Lesson plans

1. Lesson 1: PLC PRINCIPLES

   a. Information outline

2. Lesson 2: LADDER DIAGRAMS

   a. Information outline

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Johnson, Curtis D. Microprocessor Based Process Control. Englewood Cliffs, NJ: Prentice-Hall, 1984.

2. Jones, C. T., and L. A. Bryan. Programmable Controllers. Atlanta: International Programmable Controls, Inc., 1983.

3. Webb, John W. Programmable Controllers. Columbus, OH: Merrill Publishing Company, 1988.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental materials

1. To present this unit, use product-specific supplemental materials. Contact educational suppliers or local manufacturer representatives, such as those below, for assistance.

   a. Allen Bradley

   b. Cutler-Hammer

   c. Square D

   d. General Electric

e. Gould Modicon

f. Texas Instruments

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT II: PROGRAMMABLE LOGIC CONTROLLERS (PLC)

LESSON 1: PLC PRINCIPLES

I. Terms and definitions

A. Input device--mechanism connected to the programmable controller (PC) input modules for sending status information

Examples: switches, limit switches, pushbuttons and potentiometers

B. I/O module--electronic assembly of a PC that interfaces between the PC's CPU and the "outside world"

C. Ladder diagram--system of successive horizontal lines with symbols representing the logic operation of the control system. Symbols are drawn in relay logic or PC-logic form. The control contacts are to the left, and coils and functions are to the right.

D. Lamp--actual display on an operator's console

E. Limit switch--any kind of switch that is activated by part of the process. Examples are travel limit switches on machinery and thermal overload switches on motors which are "read" by the programmable controller as open or closed. These switches are opened and closed by limiting conditions.

F. Motor starter--The motor starter coil is actually an output from the controller that can go to an actual relay or other starter module to handle large motor currents and/or voltages.

G. Output device--mechanism connected to the output modules to receive status information

Examples: relay coils, lights and motor coils

H. Programmable controller (PC)--user-friendly computer that carries out control functions of many types and levels of complexity

I. Push button--used by operators, the external, momentary contact closing or opening switch

J. Relay--internal operation of the programmable controller that simulates actual relay coils and contacts

K. Simulator--external device used with a PC that represents the process to be controlled. It contains switches and signal devices, as well as discrete and analog output indicators.

L. Solenoid--magnetic coil that changes the on/off status of an output device by the movement of an iron plunger

M. Timer--device for monitoring or determining time sequences which begins at one event and causes another event to occur at the end of a specified time

II. Programmable controller operation

A. Introduction

1. A programmable controller, commonly referred to as a PC, is a solid-state device designed to perform logic functions previously accomplished by electromechanical relays, drum switches, mechanical timers, etc., for the control and operation of different manufacturing equipment. PCs are microprocessor-based systems used to control machines and processes in many areas of industry.

2. The PC was originally developed to perform only on/off machine control. This consisted of stopping and starting electric motors or energizing solenoids. PCs are now used with robot control, environmental controls in buildings, assembly machines, automated transfer lines and machine loading/unloading.

3. The advantage of PCs over relays is that relays have to be hard wired to perform a specific function for a system. When the system requirements changed, the relay control had to be changed. This may have required the entire relay bank to be physically changed or completely rewired. With the PC, this can be accomplished by simply reprogramming the controller with a hand-held programmer.

4. The requirements of modern industry require smaller, faster-acting and more reliable control devices. Programmable controllers meet this requirement.

5. PCs are designed to operate over a wide range of conditions. The PC can perform effectively with changes in temperature and humidity and are not affected by electrical noise.

6. The PC can be operated by personnel without knowledge of computers or computer technology. Another difference is that PCs are designed to be installed by plant electricians, not highly trained electronics technician.

7. Unlike the computer, the PC is programmed in **Relay Ladder Logic**, not in one of the computer languages. The PC has a memory for storing the user program or logic for controlling the process. The program can be re-entered in the system, should something happen to the program running the process.

8. Most PCs have fault indicators. Fault information is displayed on a CRT screen, which enables maintenance technicians to rapidly diagnose a system fault.

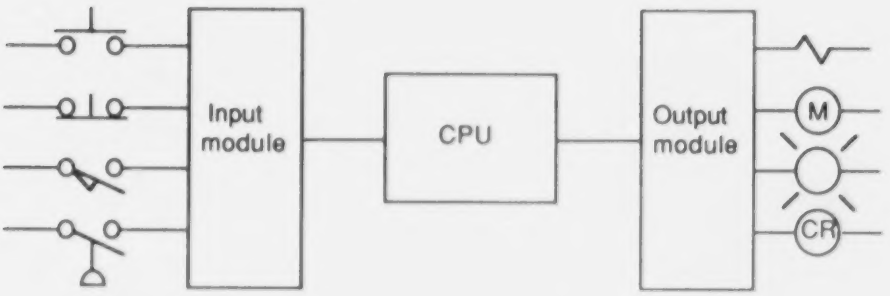
B. The programmable controller system

1. The basic components of a programmable controller are few compared to most systems. As shown in the figure below, the PC consists of a central processing unit (CPU) and input/output modules (I/O).

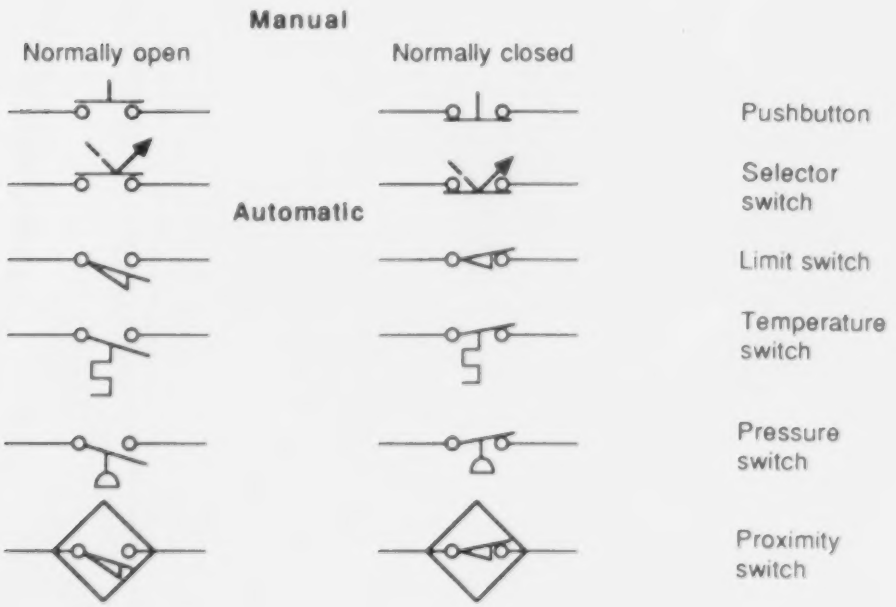
2. The CPU consists of a DC power supply, memory and a processor. As the PC runs its program, it receives inputs through the input module from such things as limit switches, pressure switches, push buttons, etc.

3. These inputs are used by the program to determine what outputs are to activated. The outputs can be connected to such devices as solenoids or indicator lights, thereby controlling pneumatic, hydraulic, electrical motors or other processes.

C. Switch contacts are classified as normally open (N.O.) or normally closed (N.C.) When a switch is operated either manually or automatically, the N.O. contacts close and the N.C. contacts open.



D. Some symbols used in ladder diagrams are shown below.



III. Output devices

A. The three types of output devices used in ladder diagrams are lights, solenoids and relays.

B. The logic diagrams for these devices are shown below.

1. Motor solenoid coil

2. Coils

3. Solenoids

4. Normally closed contact

5. Normally open contact

6. Light

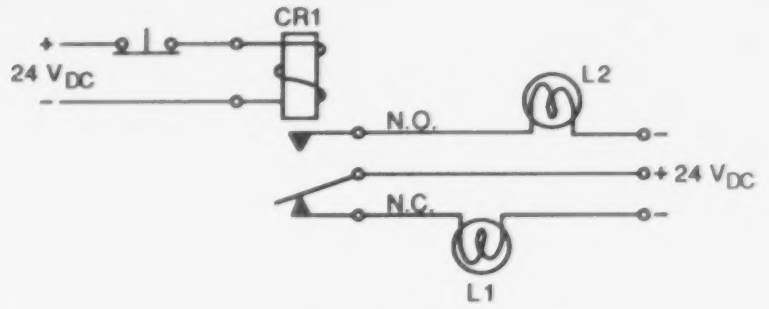
MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT II: PROGRAMMABLE LOGIC CONTROLLERS (PLC)

LESSON 2: LADDER DIAGRAMS

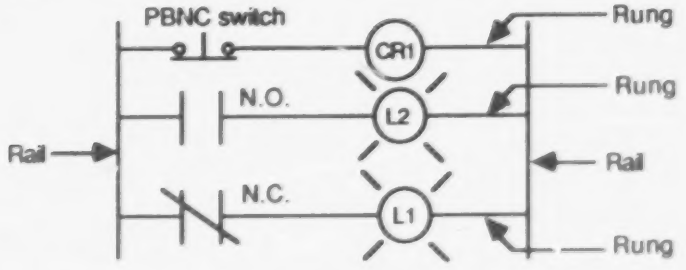
I. Introduction

A. Before microprocessors, electrical circuits were used to automate industrial machines. These circuits used relays to perform decision functions. The diagram for such a function is shown below.



Decision function

B. This function is now performed by internal logic circuits which are part of the microprocessor. The method of diagramming used with programmable controllers using a microprocessor is called ladder logic. The circuit shown below represents the same circuit as above, but in ladder diagram form.



Ladder logic

C. Follow established rules for ladder diagrams

1. All components are drawn on rungs of the ladders.
2. Each rung represents a power path showing the wire connections between the components on that rung.
3. Side rails represent power leads from the power supply.
4. The left rail is the high side and the right side is the low side.

5. Input devices on the same rung are connected in series, series-parallel or parallel to a single load.

6. When continuity exists to the load, power flows from one side of the rail to another to power the device on that rung.

7. If any contact or switch is open, power stops flowing and the output device is turned off.

8. Each rung represents an independent path.

9. Two rungs on a ladder represent two parallel, independent paths.

D. Switches are the input devices for ladder diagrams.

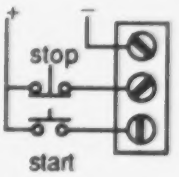
1. All ladder diagrams must have one or more input switches. These switches can be manual switches controlled by an operator or automatic switches controlled by solenoids or relays.

2. Manual switches can be either pushbuttons and/or selector switches.

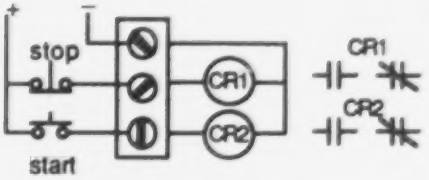
3. Examples of automatic switches are pressure, limiting, temperature and proximity switches.

II. Ladder diagram wiring

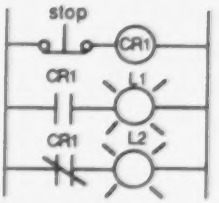
A. All devices are wired individually to terminals of an input module.



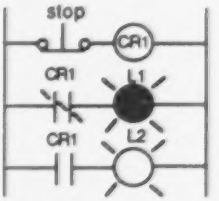
B. If each input device is connected to an imaginary relay in the input module and each relay has a N.O. and N.C. contact, a ladder diagram would be represented as shown below.



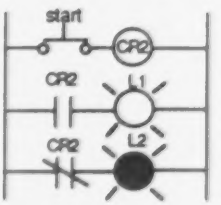
C. If a lamp is connected to the relay's normally open contact and another lamp is connected to the normally closed contact, the ladder diagram is drawn as shown to the right.



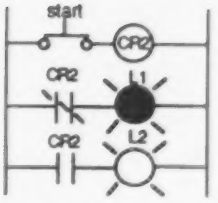
D. When power is applied, CR1 energizes through the normally closed contacts of the stop button. When CR1 energizes, the normally open contacts of CR1 close and lamp 1 will light. The normally closed contacts of CR1 will open, thereby causing L2 to be unable to light. This is shown to the right.



E. An imaginary relay has been used inside the input module. In reality, microprocessor circuitry would be controlling the light, which is an output device. In the example, a normally open start switch connected to an input terminal of a PC and a relay would not light until the start switch is closed. L1 lights only as long as L1 is held down.



F. L2 lights as soon as power is applied but goes out when the start button is closed and relay coil CR1 becomes energized, as shown to the right.



III. System ladder diagram

A. Ladder diagrams are set up in sequence to represent a process. This example will set up a diagram for starting a conveyer system in a manufacturing process.

B. The following event sequence is required.

1. With the system off, the amber light should be on.

2. The manual push-button starter causes the motor to start if the temperature switch is closed.

   a. The amber light will be off and the red light on.

   b. A 30-second timer will run.

3. When the 30-second timer runs out, the conveyer clutch engages, the red light goes off and the green light come on.

4. The manual push-button STOP causes the amber light to come on and all others to be off.

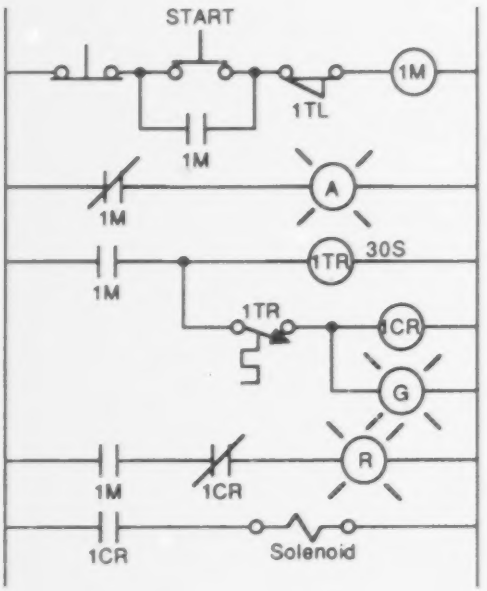
   a. Motor stops

   b. Clutch releases

C. The ladder diagram is constructed by taking each individual phase of this sequence and constructing the appropriate rung to perform the function.

D. The ladder diagram is constructed as if the system would be assembled using relays. When the PC is programmed, the relay functions are implemented by software functions. The ladder diagram below will implement the criteria for this example.

E. When programmed, the only **real inputs** will probably be the push-button switch operations and the motor thermal overload switch. The **real outputs** will be the display light signals and signals to the motor starter and clutch solenoid.



MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT II: PROGRAMMABLE LOGIC CONTROLLERS (PLC)

UNIT TEST

Match PLC symbols with their respective names.

___ 1. Motor solenoid coil

___ 2. Coil

___ 3. Solenoid

___ 4. N.C. contact

___ 5. N.O. contact

___ 6. Light

___ 7. N.O. push-button switch

___ 8. N.C. pressure switch

___ 9. N.C. proximity switch

a.

b.

c.

d.

e.

ab.

ac.

ad.

ae.

bc.

Match terms to appropriate definitions.

____ 10. Used by operators, the external, momentary contact closing or opening switch

____ 11. Internal operation of the programmable controller that simulates actual relay coils and contacts

____ 12. Device for monitoring or determining time sequences which begins at one event and causes another event to occur at the end of a specified time

____ 13. Actual display on an operator's console

____ 14. Magnetic coil that changes the on/off status of an output device by the movement of an iron plunger

____ 15. System of successive horizontal lines with symbols representing the logic operation of the control system

____ 16. External device used with a PC that represents the process to be controlled

____ 17. User-friendly computer that carries out control functions of many types and levels of complexity

____ 18. Electronic assembly of a PC that interfaces between the PC's CPU and the "outside world"

a. I/O module
b. Input device
c. Ladder diagram
d. Lamp
e. Motor starter
ab. Output device
ac. Programmable controller
ad. Push button
ae. Relay
bc. Simulator
bd. Solenoid
be. Timer

Develop a ladder diagram that will meet the following conditions.

The main goal is to develop an alarm system controlled by a PLC that will monitor four switches and give the following indications.

a. If one input switch is on, the alarm will not activate.
b. If any two inputs are on, a red light will light.
c. If any three inputs are on, an alarm siren sounds.
d. If all four inputs are on, the fire department will be notified.

To identify input and output numbers, the PC numbers will be identified as follows.

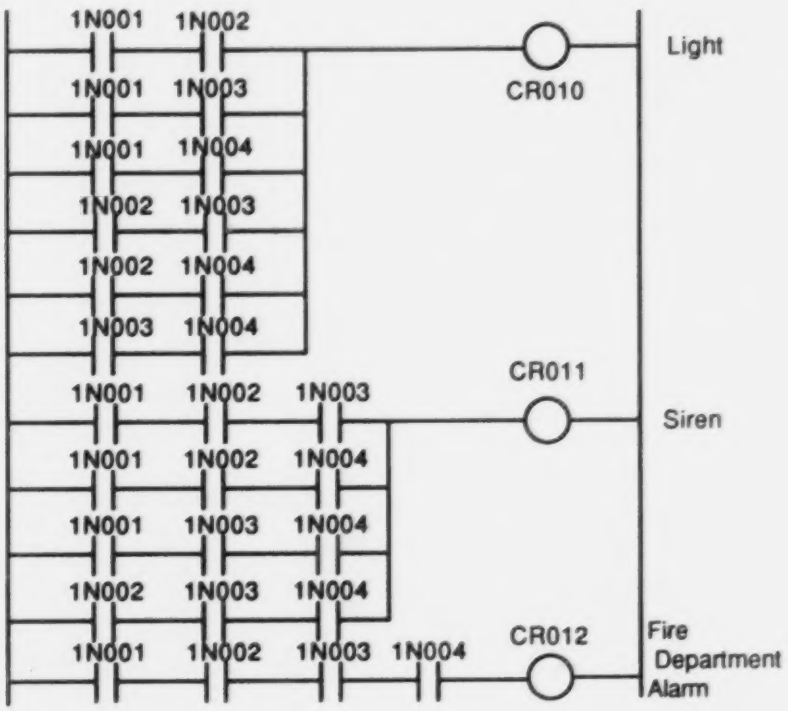
	Inputs	Outputs	
A	IN 0001	Red light	CR 0010
B	IN 0002	Alarm (siren)	CR 0011
C	IN 0003	Fire Department	CR 0012
D	IN 0004		

19. In the space below or on a separate sheet, draw the ladder diagram for the alarm system.

ANSWERS TO UNIT TEST (L9)

1.	ae	10.	ad
2.	ad	11.	ae
3.	a	12.	be
4.	c	13.	d
5.	b	14.	bd
6.	bc	15.	c
7.	ac	16.	bc
8.	d	17.	ac
9.	ab	18.	a

19. Instructor to evaluate student's diagram based on correct sequencing and symbolism.



MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT III: STEPPER MOTORS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to explain stepper motor operation and identify motor types. This knowledge will be evidenced by achieving the specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Define terms used with stepper motors.

1.2 Discuss stepper motor advantages and/or uses.

1.3 Describe the operation of and difference between a bipolar, bifilar and variable-reluctance stepper motor.

2.1 Describe different characteristics of stepper motors.

2.2 Describe stepper motor design considerations and operation.

2.3 Describe different ways stepper motors are controlled.

2.4 Test a stepper motor to determine type and operation. (competency L3, JS 1.1)

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT III: STEPPER MOTORS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: OPERATION

   a. Information outline

2. Lesson 2: SPECIFICATIONS AND TESTING

   a. Information outline

   b. Job sheet

      JS 2.1: Test a four-phase stepper motor

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Gayakwad, Ramakant, and Leonard Sokoloff. Analog and Digital Control Systems. Englewood Cliffs, NJ: Prentice-Hall, 1988.

2. Hoekstra, Robert L. Robotics and Automated Systems. Cincinnati, OH: South Western Publishing Co., 1986.

3. McComb, Gordon. Robot Builder's Bonanza. Blue Ridge Summit, PA: Tab Books, Inc., 1987.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Show different types of stepper motors to students.

2. Demonstrate stepper motor uses in computer printers and disk drives.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT III: STEPPER MOTORS

LESSON 1: OPERATION

I. Terms and definitions

A. Bifilar stepper--commonly referred to as a unipolar stepping motor; a variation of a bipolar permanent-magnet stepper motor. The difference is that in the bifilar stepper, each stator winding is center tapped, which places two stator windings on each stator pole.

B. Bipolar permanent-magnet stepper motor--contains a permanent magnetic rotor. Its operation is the result of magnetic characteristics of like poles repelling and unlike poles attracting.

C. Step angle--amount of armature rotation caused by each input pulse

D. Stepper motor--motor that can rotate in either direction, start or stop at various mechanical positions and move its rotor in precise angular increments for each input excitation step

E. Variable reluctance stepper--contains no magnet in the rotor but is constructed of soft iron and has salient poles. The number of winding phases and the number of teeth on the rotor and stator determine the step angle.

II. Stepper motor introduction

A. When voltage is applied to a DC motor, the armature turns and the armature will continue to turn as long as voltage is applied. The armature of a stepper motor does not continue to turn, but will turn a specific number of degrees and stop.

B. Stepper motors rotate a precise amount of angular distance--one step for each pulse applied in a specific sequence. For example, if a stepper motor has a step angle of 1° and it is required to rotate a shaft 45° to position an object, it would require 45 pulses applied to the stepper motor inputs in a specific sequence. (The sequence depends upon the type of stepper motor used.)

C. The advantage of a stepper motor over a standard motor is the ability to determine how far a shaft has rotated. When a stepper motor is interfaced with a computer, the computer can provide the step pulses to the stepper, thereby determining how many degrees the stepper motor will rotate.

D. Stepper motors are becoming more popular in industry applications where computer control is used. Stepper motors have significant advantages over closed-loop DC servo systems. Feedback signals are not required, and motor error is noncumulative as long as pulse-to-step integrity is maintained.

E. Stepper motors are used in robotics, milling machines, disk drives and computer printers, as well as many other applications requiring precise positioning of an item.

III. Stepper motor operation

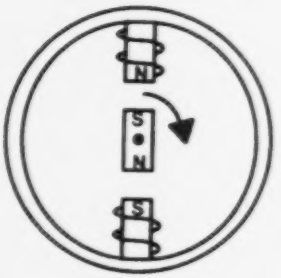
A. Three types--bipolar (permanent magnet), variable-reluctance and bifilar

B. Bipolar stepper motor

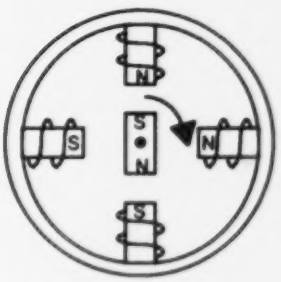
1. A simple permanent magnet motor is shown below. The motor consists of a permanent magnetic armature and a wound field. When voltage is applied to the field, the field is energized and the armature will rotate until the north pole of the armature is aligned with the south pole of the field and the south pole of armature is aligned with the north pole of the field.

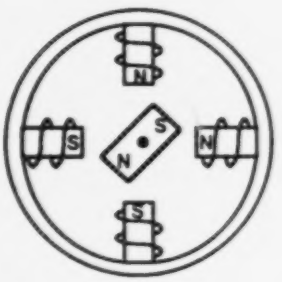
2. When this occurs, the armature is held by the magnetic field and stops rotating. For the motor to continue to rotate, the applied voltage must be reversed. When the applied voltage is reversed, the north pole of the field becomes the south pole and the south pole of the field becomes the north pole. The fields are aligned and the magnetic fields oppose one another, causing the armature to rotate until the unlike poles are aligned and the motor stops.

3. This design is not acceptable because it is not possible to determine the direction of rotation. The armature may turn clockwise or counterclockwise. To eliminate this problem, another set of field windings is added, as shown below on the left. All of the fields are energized.



Simple permanent magnetic motor

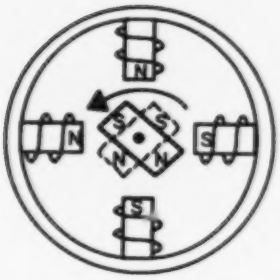


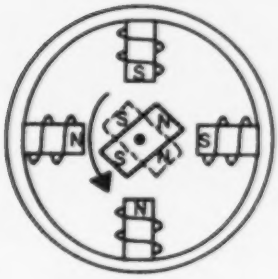


Reversible magnetic motor

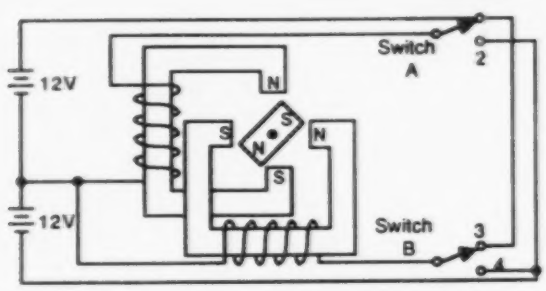
4. The figure on the right illustrates the operation of the four-pole stepping motor. The south pole of the armature is located between the two north field poles, and the north field pole of the armature is between the two south field poles.

5. When the fields change, the armature follows as shown in the left figure below, turning counterclockwise. On the right, the fields change again and the armature follows. As the pair of north fields rotate counterclockwise, the armature follows.





6. Refer to the schematic diagram and switch arrangement figure for the control of a stepper motor. One switch at a time is changed, which reverses the one pair of field magnets, and the armature rotates in a clockwise direction.



Step no.	Clockwise rotation	
	Switch A	Switch B
1	1	3
2	2	3
3	2	4
4	1	4
1	1	3

360° revolution

Stepper motor control

7. Stepper motors are normally operated to turn clockwise and counterclockwise when positioning a device.

   a. The switch closures identified above will result in a counterclockwise rotation. This type of stepping motor is called a bipolar stepping motor.

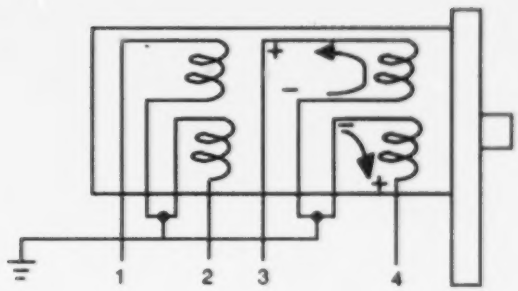
   b. A dual-power supply or applicable control circuitry is required to reverse the magnetic fields of the poles.

C. Bifilar stepper motor (unipolar stepper)

1. Another type of stepper motor is the bifilar. It is a variation of the bipolar permanent-magnet stepper motor.

2. The difference is that in the bifilar stepper motor, each field winding has been center-tapped and requires only one power supply.

3. As shown in the following illustration, when a positive voltage is applied to the top of the vertical coil, current flows through the coil to the center-tap and then to positive voltage. Only one-half of the coil is active for any switch closure.



STEP	1	2	3	4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	ON
3	OFF	ON	OFF	ON
4	OFF	ON	ON	OFF
1	ON	OFF	ON	OFF

4. Since the coil windings are center-tapped, current can be sent through alternate halves of each phase to obtain alternate magnetic polarities. When voltage is applied to the bottom of the coil, the windings of the coil appear to be in the opposite direction.

5. Voltage applied to the bottom of the coil causes current to flow through the coil from the ground. The magnetic poles then reverse. The step sequence of the motor follows a definite pattern and is easily controlled by a digital shift register circuit. The switch sequence is in the previous table.

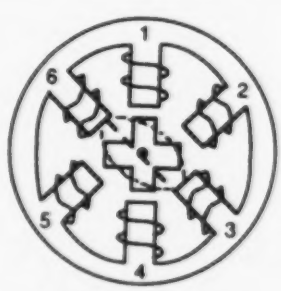
D. Variable-reluctance stepping motor

1. Another type of stepper motor is the variable-reluctance stepping motor. This type of stepper has a soft iron armature instead of a permanent magnet armature.

2. The number of winding phases and the number of teeth on the armature and coils will determine the step angle. Because the armature is not magnetized, the armature position is independent of the polarity of coil excitation. A single-ended power supply can be used with this type of stepper motor. These motors can operate at high speeds.

3. The dashed lines on the following illustration indicate magnetic lines of force. When voltage is applied to poles 3 and 6, magnetic fields originate at the poles. The soft iron armature will be pulled into alignment to complete the path for the magnetic field.

4. If the fields are turned on in order, the motor will rotate clockwise. If the fields are turned on in the reverse order, the motor will turn counterclockwise. There is no residual torque to maintain armature position when the motor is deenergized.



Variable-reluctance stepper

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT III: STEPPER MOTORS

LESSON 2: SPECIFICATIONS AND TESTING

I. Stepper motor characteristics

A. The basic DC motor is not a precise device. Without a servo feedback system or tachometer, it is difficult to tell how fast the DC motor is turning. It is also difficult to make a DC motor rotate a specific number of turns.

B. Robots and milling machines may require a motor to turn a specific number of turns for complete accuracy. Stepper motors meet these requirements. Instead of having a continuous voltage applied as a DC motor, stepper motors are driven by electrical pulses. Each pulse causes the stepper motor shaft to turn a certain number of degrees.

C. The most popular type of stepper motor is a four-phase stepper. The four-phase stepper contains two motors sandwiched together. Each motor contains two windings. Wires connect to each winding with the commons connected together. Normally, five or six wires will extend from the stepper motor for external connections.

II. Stepper motor design considerations and operation

A. Design considerations

1. All stepper motors have at least two phases. Normally, the more phases a stepper has, the better its accuracy.

2. Step angles vary with 1.7-90° being the most common. The step angle determines the number of steps per revolution. A stepper with a 1° step would require 360 steps for a 360° revolution, while a stepper with a 1.8° step angle would have to be pulsed 200 times for a complete revolution.

3. Steppers operate better at lower speeds since the slower it revolves, the higher the torque. Compared to the same size DC motor, stepper motors cannot deliver as much torque.

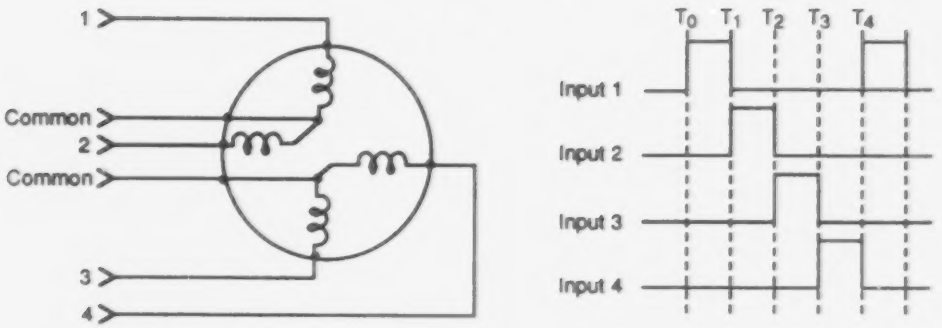
4. Stepper motors have their own stopping or braking system. When a voltage pulse is applied in the correct sequence to a winding of a stepper motor, it turns. If voltage is continually applied to this winding, the motor will not turn. For this reason it is unnecessary to add a braking circuit to a stepper motor.

5. Stepper motors vary in voltage and current ratings. Voltages of 5, 12 and 24 volts are common. Using a higher voltage than specified does not result in faster operation but will increase torque. Care must be taken when increasing voltage because the stepper can be destroyed.

6. A stepper's current rating is expressed in amps per phase. The power supply should be capable of delivering twice this value for safe operation.

B. Operation

1. The common wires of the stepper are normally tied to a positive voltage. Each winding is energized in sequence by applying a negative voltage for a short period of time. The motor shaft turns a certain number of degrees for each pulse.



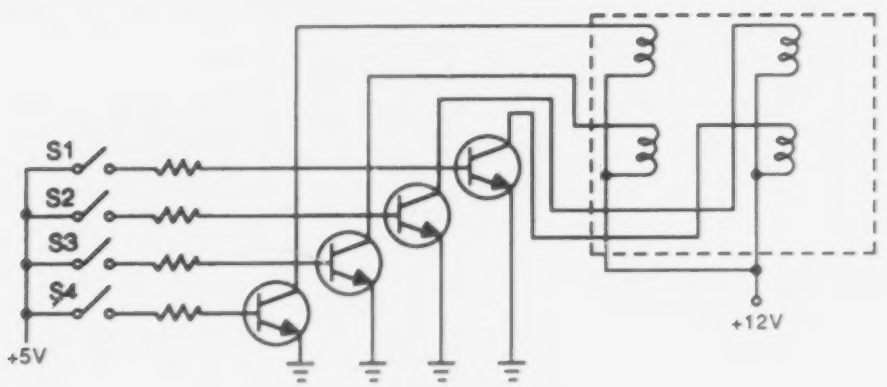
2. The previous figure shows the schematic diagram of a four-phase stepper. For correct operation, the winding pulses must be applied in the correct sequence. Always find this sequence in manufacturer's data sheets as it differs for different steppers. The right figure shows the pulse train applied to the four-phase steppers in the left illustration. Phase 1-4 should be energized in sequence.

III. Stepper motor control

A. Stepper motors can be controlled by mechanical switches, solid-state devices or LSI-controller integrated circuits.

B. Signetics and Sprague produce an LSI stepper motor I.C. The Signetics SAA-1027 and the Sprague UCN 4202 I.C.s are specifically designed for use with four-phase steppers.

C. Shown below is a schematic diagram using transistors and switches to control a four-phase motor. Applying a positive voltage in sequence as shown in the table will step the motor.



Four-phase control by transistors and switches

Step no.	Switch settings			
	S1	S2	S3	S4
1	on	off	off	off
	+5V	0V	0V	0V
2	off	on	off	off
	0V	+5V	0V	0V
3	off	off	on	off
	0V	0V	+5V	0V
4	off	off	off	on
	0V	0V	0V	+5v

D. TTL or CMOS chips can also be used to construct a stepper motor control circuit. In the event the stepper motor uses a high current, transistors should be used between the I.C. and stepper motor.

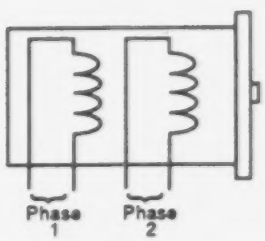
IV. Testing stepper motors

A. Wiring diagrams

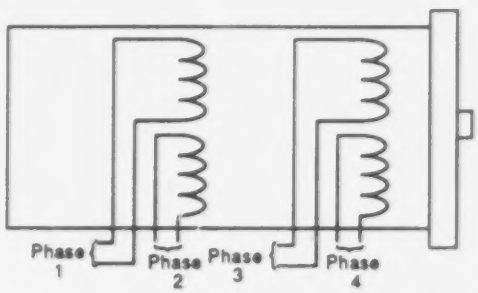
1. Stepper motors can be very expensive if bought directly from a manufacturer. The best place to purchase a stepper motor for teaching or small projects is from surplus electronic parts distributors.

2. One of the main disadvantages of buying a surplus stepper motor is that the company usually does not provide a wiring diagram.

3. The wiring diagram of two-phase and four-phase steppers follows.



Two-phase

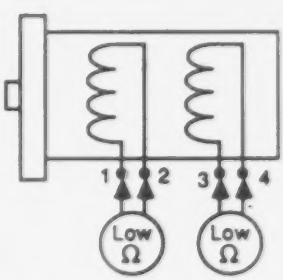


Four-phase

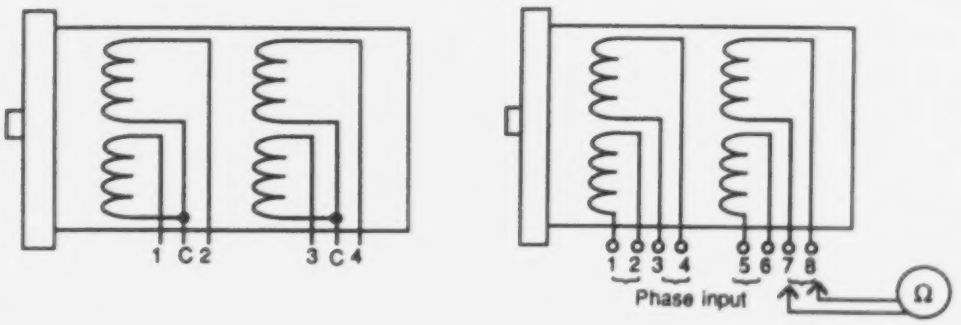
B. Testing a stepper motor

1. A two-phase motor normally has only four wires coming from the motor housing. The phases can be identified by connecting an ohmmeter between two wires. When a low resistance is indicated, this will be a phase input. Two different phases should be identified as shown in the figure to the right.

2. A four-phase motor may be more difficult. Testing is also accomplished by using an ohmmeter. If the motor has eight wires, as shown in the following figure, connect the meter the same as for a two-phase motor. Locate four matching pairs, which will identify the four phases.



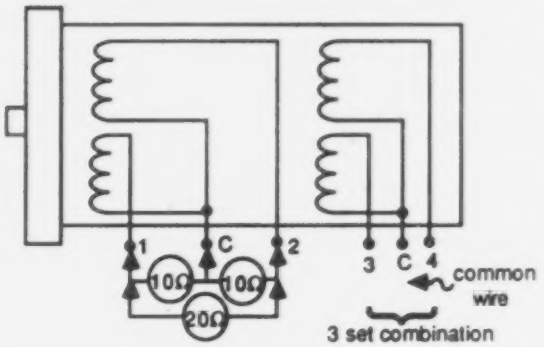
Two phase



3. Some four-phase motors may have five of the six wires coming from the housing. Four of these windings will connect to one side of individual windings, and the other one or two remaining wires will be common and connect to the other side of the windings, as shown in this figure.

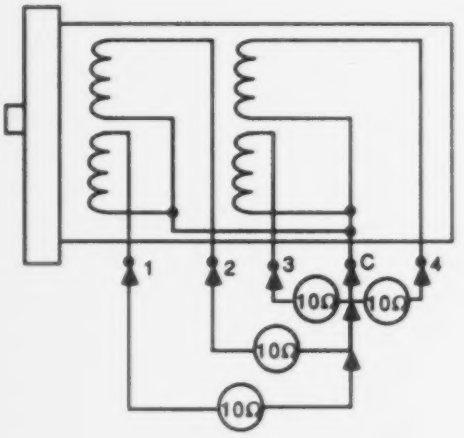
4. Decoding the wiring scheme may require some patience. There should be two three-wire sets.

5. To locate the common wire, take resistance measurements of each three-set combination of wires as shown in the following figure. Two of the combination readings should be the same, and the third should be double the resistance. The same readings will be two main windings. The doubled reading will indicate both windings. The wire that was common to the two same readings will be the common wire.



Three-set wire combination

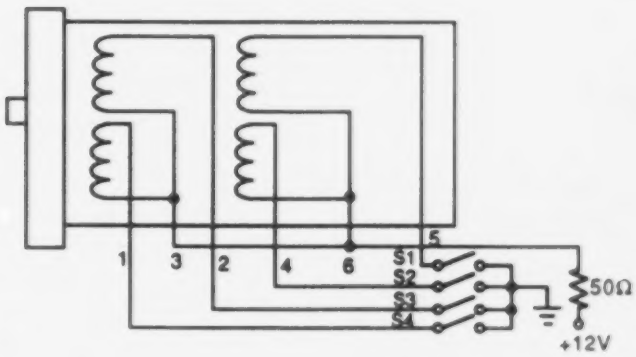
6. Testing of a five-wire stepper is shown in this figure. Measure each wire combination and note the results of each. The common wire is indicated when the same resistance is measured between one wire and the other four. The other four remaining wires indicate input phases.



TEST A FOUR-PHASE STEPPER MOTOR

Equipment:

DC four-phase stepping motor
12V power supply, 1A
50Ω, 1/2 watt resistor
Logic switches (4)



Procedure:

		Evaluation 3	2	1	N
1.	Using an ohmmeter, identify common wires and four-phase windings of the stepper motor.	—	—	—	—
2.	Construct the manual switching control circuit for a DC stepping motor shown in the figure above.	—	—	—	—
3.	Check manufacturer's data sheets to determine that phase 1 is connected to logic switch 1, phase 2 is connected to logic switch 2, etc.	—	—	—	—
4.	Turn on the DC power supply and apply 12V while leaving all logic switches open.	—	—	—	—
5.	Make a position location pointer (paper clip, etc.) and attach to the stepper motor shaft.	—	—	—	—
6.	Using the logic switches, fill in the following table for four full steps of the stepper.	—	—	—	—

Step no.	Switch settings S1	S2	S3	On/off S4
1				
2				
3				
4				

7.	Note the direction the stepper moves and its initial location.	—	—	—	—
8.	Step the motor through 360°.	—	—	—	—
9.	Calculate the step angle.	—	—	—	—
10.	Using data switches, control the stepper so that it goes into the opposite rotation.	—	—	—	—
11.	Turn off the power supply and remove parts from the circuit.	—	—	—	—
Average of above evaluations*		—	—	—	—

*This average is the student's final evaluation for competency L3: Test and repair a stepper motor.

NOTE: Due to inexpensive replacement costs, the repair of a stepper motor is uncommon since it's more practical to replace it than repair it.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT III: STEPPER MOTORS

UNIT TEST

Select the option which answers the question or completes the statement.

___ 1. How do stepper motors rotate?

a. Clockwise or counterclockwise
b. Only counterclockwise
c. Only clockwise
d. Same as a conventional DC motor
e. In any direction

___ 2. Which describes the variable-reluctance stepper motor?

a. Functions the same as the bifilar stepper motor
b. Functions the same as the permanent-maget bipolar stepper motor
c. Contains no permanent magnets
d. Can move only in the clockwise direction
e. Can move only in the counterclockwise direction

___ 3. What is one difference between the bifilar and bipolar stepper motors?

a. The bifilar motor contains no magnets.
b. The bipolar stepper contains no magnets.
c. The bifilar stepper has center-tapped stator windings.
d. The bipolar stepper has center-tapped stator windings.
e. The bipolar motor requires only one power supply.

___ 4. Which term refers to the amount of armature rotation of a stepper motor?

a. Input pulse width
b. Step angle
c. Closed-loop servo
d. Feedback signal
e. None of the above

___ 5. When one pulse is applied to the proper stepper motor winding, what does the stepper motor do?

a. Rotate 360° and stop
b. Starts to turn and continues until the pulse is removed
c. Advances a precise angular distance
d. Stops
e. Provides feedback signals

___ 6. What is one advantage of a stepper motor over a standard DC motor?

a. Ability to determine how far the shaft has rotated
b. Increased speed
c. Ability to rotate counterclockwise
d. Production of a feedback signal for stopping rotation
e. All of the above

___ 7. Why do stepper motors have a significant advantage over closed-loop servo systems?

a. Motor error is noncumulative.
b. Feedback signals are not required.
c. Braking circuits are not required.
d. All of the above
e. None of the above

___ 8. Which devices can be used as stepper controllers?

a. Logic switches
b. Shift registers
c. Computers
d. All of the above
e. None of the above

___ 9. Which instrument is used to identify the phases of a stepper motor?

a. Ohmmeter
b. Voltmeter
c. Flow meter
d. Capacitive meter
e. None of the above

___ 10. How are current ratings of stepper motors expressed?

a. Henries
b. Ohms/volts
c. Farads
d. Amps/volts
e. Amps per phase

___ 11. Which type of motor is preferred for robots and milling machines?

a. Basic DC motor
b. Basic AC motor with tachometer
c. AC motor with servo feedback
d. Stepper motor
e. None of the above

ANSWERS TO UNIT TEST (L3)

1. a
2. c
3. c
4. b
5. c
6. a
7. d
8. d
9. a
10. e
11. d

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT IV: DIGITAL CONTROL SYSTEMS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to explain the operation of a basic digital control system and identify the main parts of a digital control block diagram.

SPECIFIC OBJECTIVES

Upon completion of the lesson in this unit, the student will be able to:

1.1 Define terms and definitions associated with digital controls.

1.2 Describe the basic parts of a digital control block diagram.

1.3 Explain the basic operation of a digital light control system. (competency L6, JS 1.1)

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT IV: DIGITAL CONTROL SYSTEMS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: DIGITAL CONTROLS

   a. Information outline

   b. Job sheet

      JS 1.1: Construct and test a light-intensity digital control circuit

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Gayakwad, Ramakant, and Leonard Sokoloff. Analog and Digital Control Systems. Englewood Cliffs, NJ: Prentice-Hall, 1988.

2. Harrington, John. Automated Process Control Electronics. Albany, NY: Delmar, 1989.

3. Maloney, Timothy J. Industrial Solid State Electronics. 2nd ed. Englewood Cliffs, NJ: Prentice Hall, 1986.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. The subject of this unit was chosen because controlling a light's intensity is common to all studying electronics. A short lecture on light control in theaters, stage shows and offices may motivate students to learn more about digital control of lighting.

2. Demonstrate a digital-controlled light system or other controlled devices.

3. SAFETY NOTE: In JS 1.1, there is 117V AC present in the circuit. It is recommended that the MOC3030, TRIAC and associated circuitry be placed into a project box to eliminate the possibility of student contact with the 117V current. Set it up so the MOC3030 and bridge rectifier outputs are available on the project box.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT IV: DIGITAL CONTROL SYSTEMS

LESSON 1: DIGITAL CONTROLS

I. Terms and definitions

A. Control module--unit of a digital control system that processes binary signals from the input and set-point modules to actually control the operation and timing of the device

B. Input module--unit of a digital system which provides operating voltage for the input transducers (if used) and an analog-to-digital converter (if necessary) to convert the input signal to binary

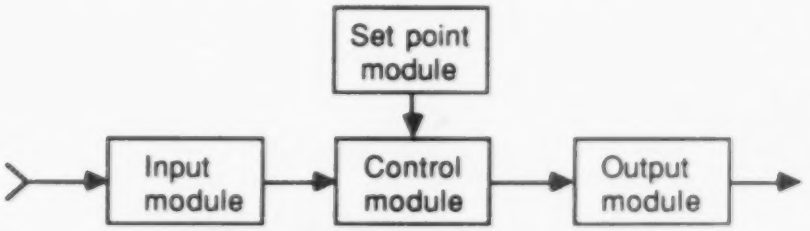
C. Output module--drives the actuator or device based on decisions made in the control module

D. Set-point module--unit of a digital control system which accepts inputs from an operator to control the timing of the digital control

II. Digital control block diagram

A. Digital process controllers have begun to dominate the industrial market. Digital temperature controls, appliance timers (i.e. microwave ovens), digital motor speed controls, stepper motor position control and light-intensity are just a few uses of digital control systems.

B. The basic parts of a digital control circuit are shown below.



Digital control circuit block diagram

1. The input module provides operating voltages for input transducers and analog-to-digital converters, if used in the system. Input modules are available for DC or AC voltages, rate-of flow variable frequency inputs, thermocouple inputs and other types of analog signals.

2. The set-point module allows the operator to input to the system. This input can be supplied by a computer keyboard, BCD thumbwheel switches, DIP switches or potentiometer settings. These settings are converted into a binary value for the control module.

3. The control module processes binary signals from the input and set-point modules. This module performs timing and decisions for the entire system.

4. The output module drives the actuator device according to instructions from the control module. This device can be circuitry and/or relay contact closures, TRIAC on-off control, liquid or air valve closure.

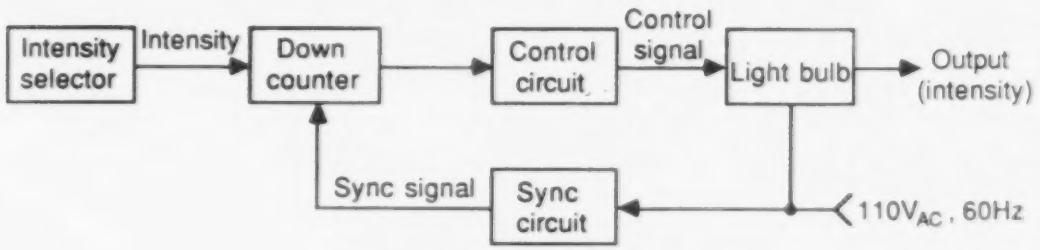
5. The controlled device can be a light bulb's intensity, heat of a hand-held hair dryer, a microwave oven's heating time, motor speed or machine operation.

III. Digital light control system

A. Often it is necessary to control a light's intensity or for lights to come on and turn off at specific times. Depending on how it is used, the control of lights can be cost-effective.

B. A light's intensity is varied by controlling the voltage applied to the light. If the light is AC operated, the on-time for the lamp can be managed by controlling the conduction angle of the 360° sine wave with a TRIAC.

C. The block diagram shown below represents a light-intensity digital control system.



Light-intensity digital control system

1. DIP switches can be the input intensity selector, controlling the input information to the digital control module on the desired intensity for the lights.

2. The load is a light bulb operated from a standard AC line voltage.

3. A down counter is used that can be loaded from the intensity selector with a BCD number of 0-99.

4. A constant intensity corresponding to a certain BCD number is necessary, so a signal that is synchronized with the 110V AC, 60Hz line voltage is required. This sync signal is used to load the number into the counter, which requires a block labeled "sync signal circuit".

5. The control circuit block processes the down counter's output to drive the light bulb.

6. The final block represents the light to be controlled. The control circuit's output regulates the output intensity of the light by controlling the input AC sine wave.

D. A digital light control system's schematic diagram can be understood best if it is examined block by block.

1. The intensity selector diagram follows.

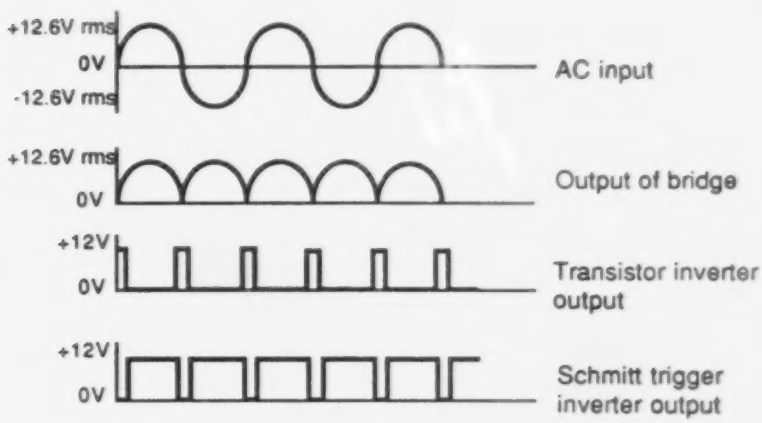
a. This circuit permits the user to select a certain intensity for the light. The intensity is set with two BCD DIP switches representing BCD numbers 00-99, where 00 represents the brightest and 99 representing the dimmest.

d. With a clock frequency of 11.9KHz, it will take the counter approximately 8.33ms to reduce BCD 99 to 0. The brightest intensity occurs when 00 is loaded into the counter.

3. The sync circuit lets the system maintain constant light intensity. This circuit is also shown in the down counter illustration.

   a. To permit constant light intensity, the same BCD number needs to be loaded at a specific time during the AC cycle. The maximum time permitted for the counter to count any number (00-99) down to 0 is 8.33ms.

   b. The synchronous preset enable ($\overline{SPE}$) input signal is derived from the 110V AC, 60Hz line voltage. A step-down transformer, full-wave bridge rectifier and invertor is used for this circuit.



Sync signal and associated waveforms

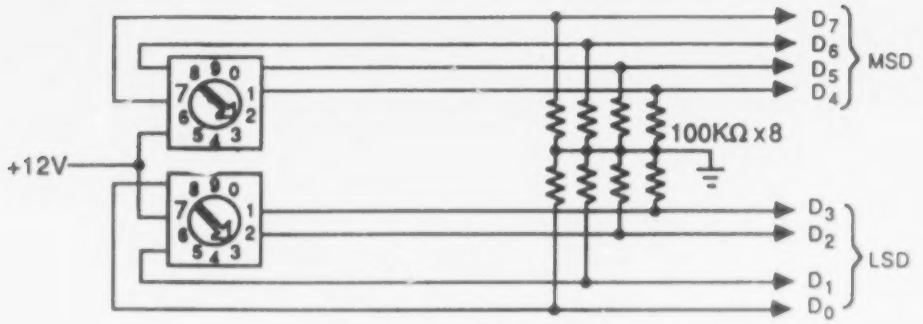
4. It is necessary to use the output of the down counter, $\overline{CO}/\overline{ZD}$, to vary the voltage applied to the light bulb so that its intensity can change. A control circuit performs this function.

   a. The control circuit consists of a voltage-to-current converter, an optically isolated TRIAC driver and a TRIAC.

   b. The output CO/ZD goes low in $\leq$8.33ms, based on the BCD number (00-99) loaded into the counter. When $\overline{CO}/\overline{ZD}$ goes low, an optically coupled TRIAC driver turns on and triggers the other TRIAC.

   c. The light bulb will now turn on. The light's intensity will depend upon the time that $\overline{CO}/\overline{ZD}$ output goes low during the 0-8.33ms. The lower the number, the brighter the light will be; the larger the number, the dimmer the light will be.

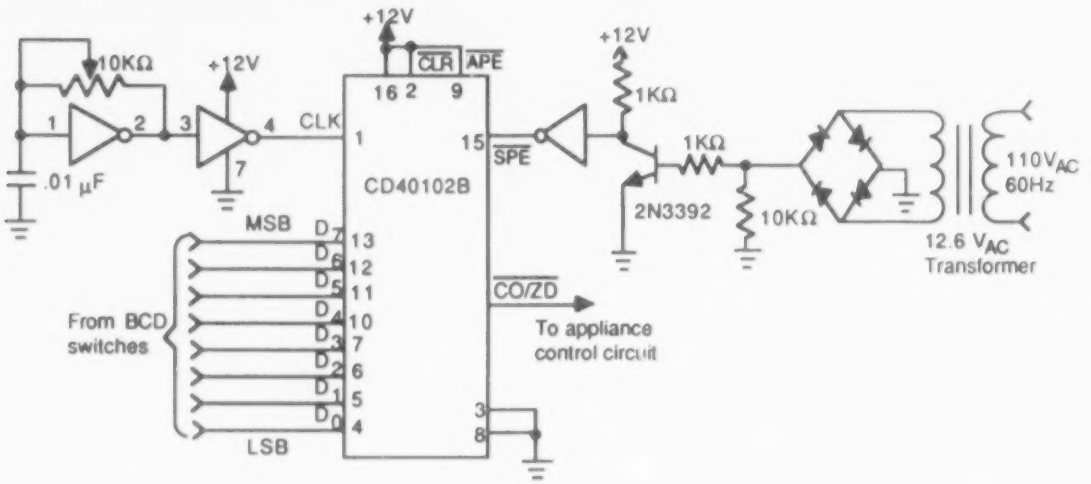
   d. The final part of the schematic is the light bulb.



Intensity selector diagram

b. When 00 is loaded into the down counter, the output is 0. This turns on the alternation at the earliest possible moment and the light is the brightest. When 99 is loaded, the opposite action occurs.

2. The down counter shown below requires two important considerations--input clock frequency and mode of operation.

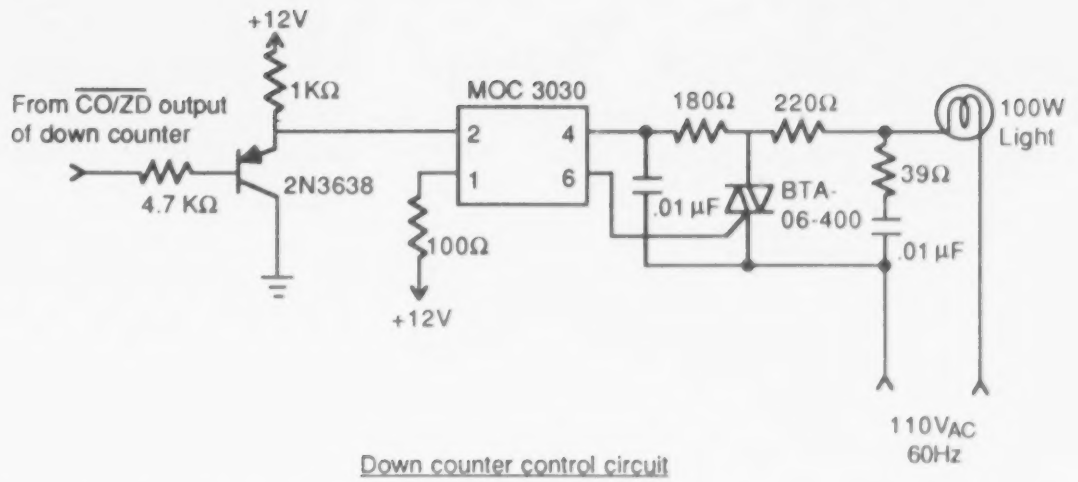


Down counter

a. The clock circuit shown consists of a 74C14 I.C. Frequency for the clock is determined by what type of device or devices are used to control the light. This example will use an opto-coupled TRIAC driver and a separate TRIAC to perform this function.

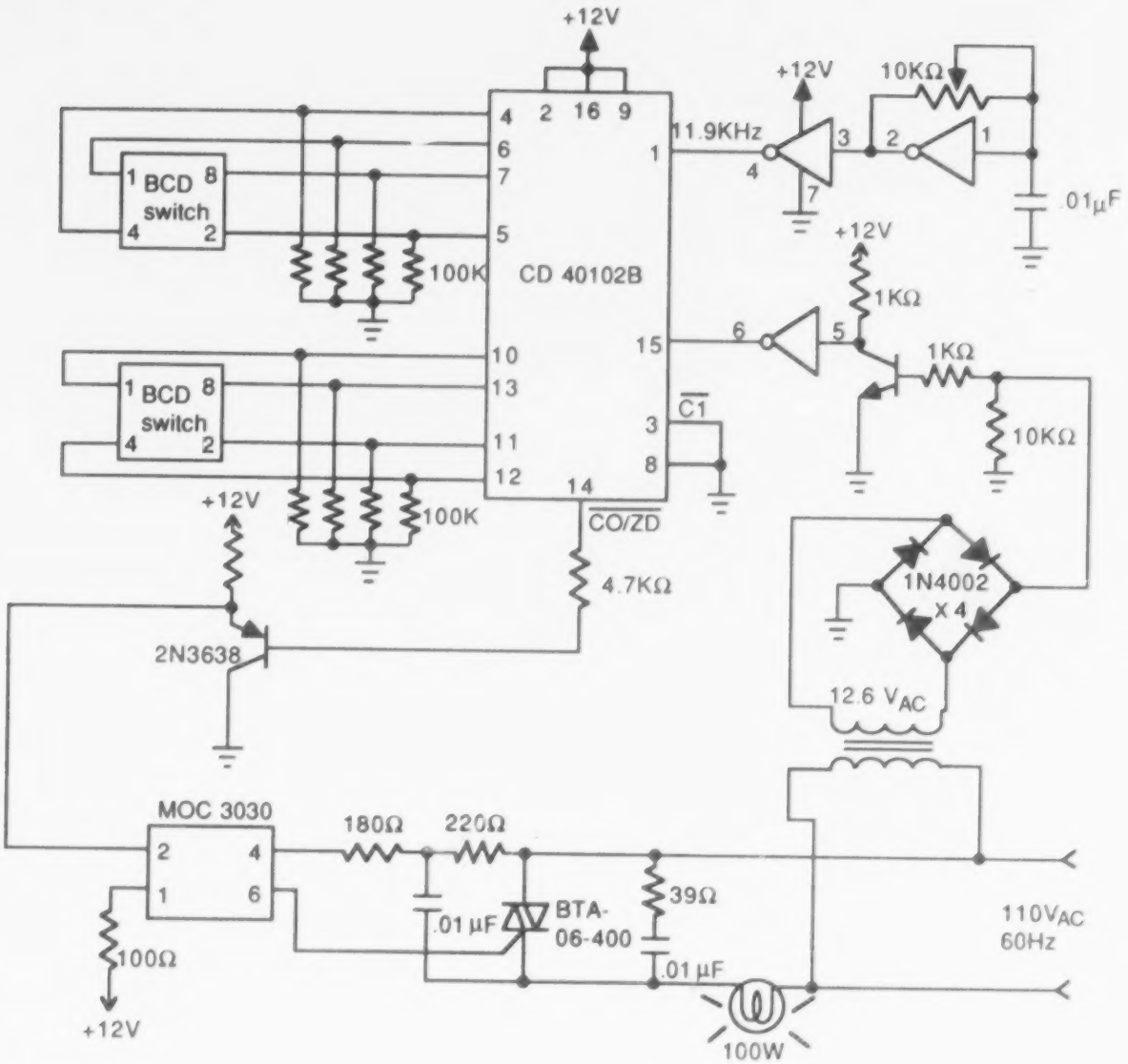
b. Determine the operation of a TRIAC over a half-cycle of 110V AC, 60Hz sine wave only. The time it takes the counter to decrement to zero is 8.33ms (or 180°). Since the maximum BCD that can be loaded is 99 and the maximum time required is 8.33ms, the required frequency of the clock is 8.33ms = 84.μS = 11.9KHz.

c. The clock circuit consists of a 74C14 hex invertor, a 0.01μF capacitor and a 10KHz variable resistor. The extra invertor permits a spike-free circuit.



Down counter control circuit

E. A complete diagram of the system follows. The CD40102 down counter is loaded every 8.3ms and decremented on each low-to-high clock transition. When the counter is decremented to zero, its output changes from high to low. This action triggers the TRIAC driver and the TRIAC, which causes the light to come on. The counter is loaded again when the SPE goes low, and the cycle is repeated. Thus, the light intensity depends on the input BCD value.



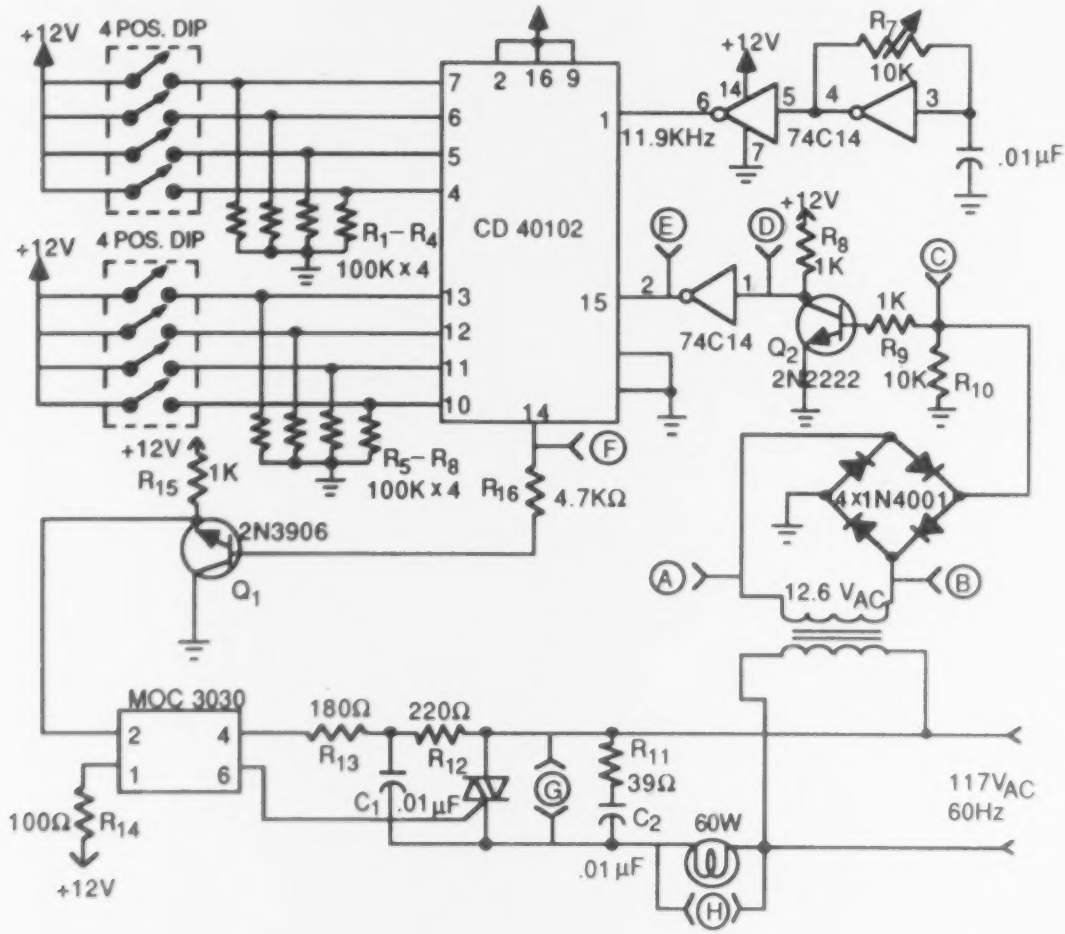
Complete digital light control system

CONSTRUCT AND TEST A LIGHT-INTENSITY DIGITAL CONTROL CIRCUIT

Equipment:

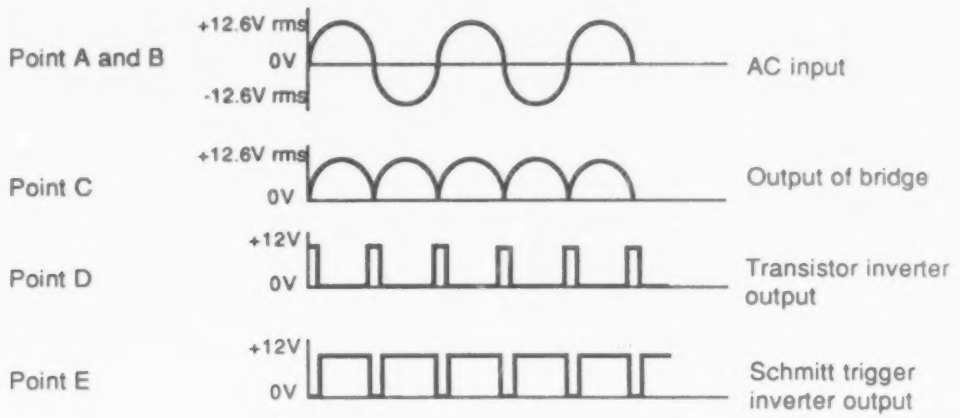
Solderless circuit board
Oscilloscope
DVM
12V DC power supply
Four-position DIP switch (2)
Resistors: 39Ω, 180Ω, 220Ω, 1KΩ (3), 4.7KΩ, 10KΩ, 100KΩ (8)
10KΩ potentiometer

I.C.s: CD40102, 74C14, MOC3030
Transistors: 2N2222 NPN, 2N3906 PNP
1N4001 diode (4)
Transformer, 117/12.6V AC, 1A
TRIAC
60W lightbulb
0.01μF capacitor (2)

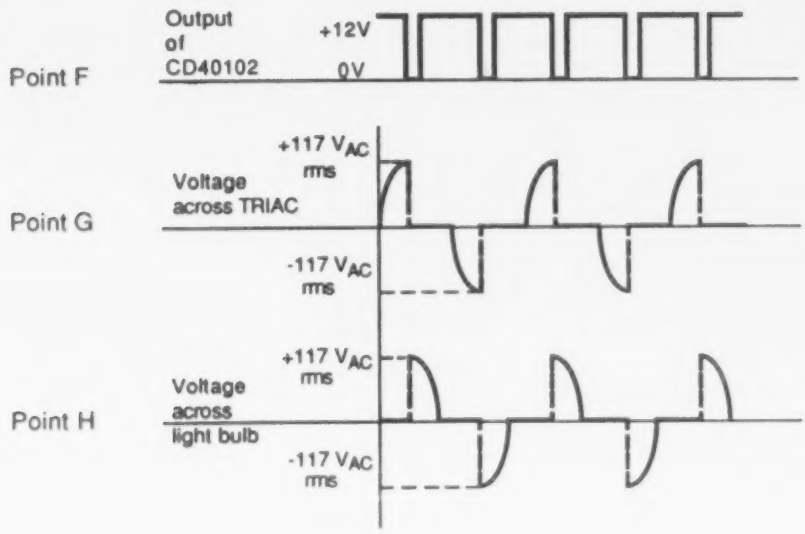


WARNING: Be extremely careful when constructing this circuit. There will be hazardous voltage present when the circuit is activated.

Procedure:	Evaluation 3	2	1	N
1. Construct the circuit shown on a solderless circuit board. Ask the instructor to check your circuit after completion.	—	—	—	—
2. After receiving instructor approval, apply power to the circuit.	—	—	—	—
3. Set the frequency of the 74C14 I.C. oscillator by adjusting R_7 to 11.9KHz.	—	—	—	—
4. Using the oscilloscope, measure the following points and observe for waveforms indicated.	—	—	—	—



5. **Measure the points indicated for the waveforms shown. If these waveforms are present, your circuit has the necessary waveforms to operate.** — — — —



6. Set DIP switches for a binary 0000 0000. The light should be the brightest. — — — —

7. Set DIP switches for a binary 1111 1111. The light should be the dimmest. — — — —

8. Set DIP switches for a binary 1000 1000. The light should become brighter. — — — —

9. Ask the instructor to check and grade your circuit. After receiving permission, tear down the circuit and return components. — — — —

Average of above evaluations* — — — —

*This average is the student's final evaluation for competency L6: Test and repair digital electronic control devices.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT IV: DIGITAL CONTROL SYSTEMS

UNIT TEST

Select the option which answers the question or completes the statement.

___ 1. Which unit provides operating voltage for the transducers?

a. Input module
b. Set-point module
c. Control module
d. Output module
e. Actuator module

___ 2. Which unit accepts input from an operator to control the timing of the digital control?

a. Input module
b. Set-point module
c. Control module
d. Output module
e. Actuator module

___ 3. Which unit drives the actuator based on decisions made in the control module?

a. Input module
b. Set-point module
c. Control module
d. Output module
e. Actuator module

___ 4. Which unit processes the binary signals from the input and set-point modules?

a. Transducer module
b. Actuator module
c. Control module
d. Output module
e. Decision module

___ 5. What are input modules available with?

a. DC voltage only
b. AC voltage only
c. DC or AC voltage
d. Frequency control only
e. DC and frequency control

___ 6. Where are inputs to the set-point module from?

a. Computer keyboard
b. DIP switches
c. BCD thumbwheels
d. Potentiometer settings
e. All of the above

___ 7. What can the actuator drive?

a. Relay
b. Circuitry
c. TRIAC
d. Pneumatic valve
e. All of the above

___ 8. An actuator can control which device?

a. Lightbulb
b. Microwave oven heating time
c. Speed of a motor
d. Machine operation
e. All of the above

___ 9. When controlling a light's intensity, what would a binary 1111 1111 represent?

a. Brightest control of the light
b. Dimmest control of the light
c. Nearly the brightest control of the light
d. Nearly the dimmest control of the light
e. Average brightness of the light

___ 10. What is the light's brightness controlled by?

a. Sine wave conduction angle
b. 60Hz signal
c. 117V AC input
d. Actuator
e. None of the above

ANSWERS TO UNIT TEST (L6)

1. a
2. b
3. d
4. c
5. c
6. e
7. e
8. e
9. b
10. a

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT V: MOTOR SPEED CONTROL

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to identify and explain the operation of a digital DC motor speed-control system. Competencies will be demonstrated by achieving the specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify and explain the purpose of each block in a block diagram of a digital DC motor speed-control system.

1.2 Identify and explain the circuit analysis in a digital DC motor speed-control system.

2.1 Explain basic considerations for DC motor speed control.

2.2 Construct and test a digital DC motor speed-control system. (competency L8, JS 2.1)

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT V: MOTOR SPEED CONTROL

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: DIGITAL DC MOTOR SPEED CONTROL

   a. Information outline

2. Lesson 2: OPTICAL DC MOTOR SPEED CONTROL

   a. Information outline

   b. Job sheet

      JS 2.1: Test optoelectronic speed control

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Gayakwad, Ramakant, and Leonard Sokoloff. Analog and Digital Control Systems. Englewood Cliffs, NJ: Prentice-Hall, 1988.

2. Hunter, Ronald P. Automated Process Control Systems. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, 1987.

3. Maloney, Timothy J. Industrial Solid State Electronics. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, 1986.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Components for constructing the circuits in this module are inexpensive and will make interesting projects for the advanced digital student. Components are available at nearly any electronics supplier. Ready-made components are also available, but the student will gain a more thorough understanding of motor speed controllers by using discrete components.

2. The speed-control circuits shown in this unit can be controlled by a computer, as well.

3. Once the student has the circuits operational and understands the theory of operation, the instructor can insert problems to advance the student's troubleshooting skills.

B. Suggested student activities

1. This unit also gives the student a chance to use the oscilloscope to test the operation of various stages which work together to form a digital system.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

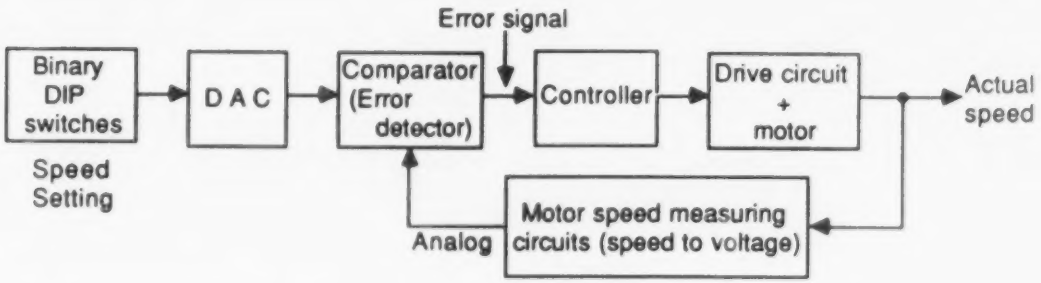
UNIT V: MOTOR SPEED CONTROL

LESSON 1: DIGITAL DC MOTOR SPEED CONTROL

I. System specifications and block diagram

A. In a digital DC motor speed-control system, certain considerations are very important: type of digital system to control motor speed, method of maintaining constant speed for periods of time, performance, accuracy and cost.

B. The block diagram of the digital motor speed-control system is shown below.



Digital motor speed control

1. The input to the system consists of eight DIP switches to set the required speed of the DC motor. These switches represent a binary code that controls the motor speed.

2. The purpose of the DAC block is to convert binary code to an analog voltage so that it can be compared to another signal, which represents the speed of the motor.

3. The DAC analog signal output is compared to the actual motor speed signal by an error-detector circuit.

4. The error-detector output is applied to the controller, which transforms and processes the error signal to control the motor speed.

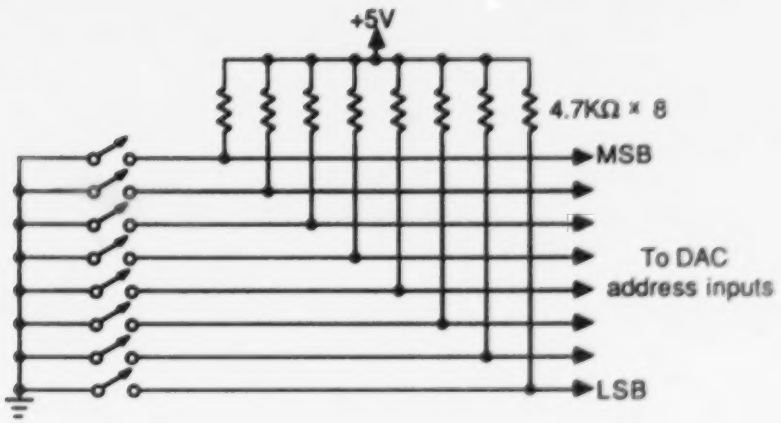
5. The motor control block contains the motor drive circuitry and DC motor. This circuitry's output is the actual rpm speed of the motor.

6. The last block in the system contains the motor measuring circuits. These circuits sense the actual motor speed and convert it into a signal that can be compared to the setting of the eight DIP switches. The difference between these two voltages is used to control the motor speed.

II. Digital motor speed-control schematic analysis

A. Input eight-position DIP switch

1. The following schematic diagram represents the eight-position DIP switch used to set the speed of the motor.

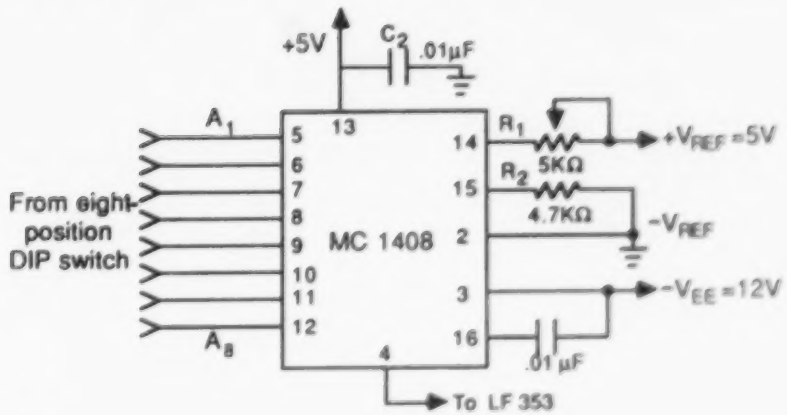


Eight-position DIP switch

2. Speed can be changed by altering the switch position. Binary numbers represented by the switches range from 0000 0000 to 1111 1111. This permits the motor speed to vary from a minimum to a maximum value or by 256 different speeds.

B. Digital-to-analog converter

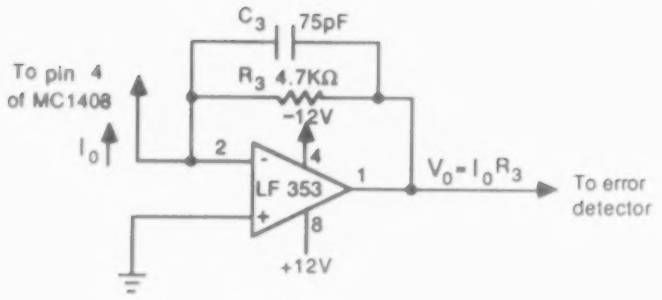
1. A digital-to-analog conversion is necessary to change the binary output of the eight-position DIP switch. This is necessary because the operating speed of the motor must be continually compared with the desired speed. Since the motor speed is analog in nature, the digital control bits must be converted to an analog voltage. The circuit for this is shown in the DAC circuit figure.



DAC circuit

2. The MC1408 DAC is used in this circuit to change the switches' digital code to an analog signal. An LF353 op amp is used to change current to voltage, as shown below.

52



3. The current output of the circuit can be calculated for any switch setting by using the formula:

$$I_O = \frac{+Vref}{R_1} \frac{N}{256}$$

Where +Vref = positive reference voltage (+5V)
R_1 = resistor connected to pin 14 and Vref
N = binary number in decimal

4. The output current (I_O) must be converted into voltage so that it can be compared with the motor speed feedback voltage. This is accomplished by the LF353 at the output of the DAC. The output voltage can be calculated by the formula: $V_O = I_O R_3$

$$= \frac{+Vref}{R_1} \frac{N}{253} R_3$$

5. R_3 is the load resistor, which equals 4.7KΩ, and C_3 and R_3 reduce ringing and overshoot problems.

6. R_1 of the DAC should be adjusted so that V_O reads +5V when the input switches are set for binary 1111 1111 (the maximum output for the DAC). This results in a resolution of 5V / 256 = 19.5mV.

7. The range of outputs for the DAC is 19.5mV to 5V as the switches' binary number ranges from 0000 0001 to 1111 1111.

C. Comparator/error detector

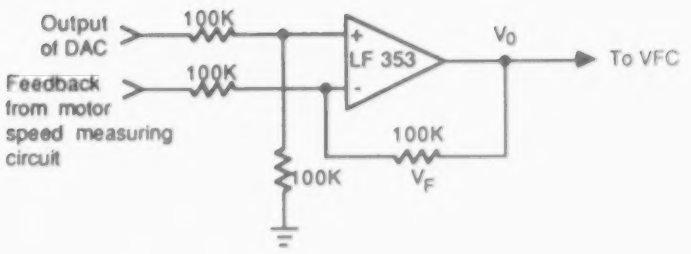
1. Required motor speed is set by the DIP switches and is converted to an analog signal by the DAC. The actual motor speed is converted into voltage by a speed-to-voltage converter.

2. To maintain the desired motor speed, these two voltages must continually be compared and corrected by an error detector.

3. The error-detecting circuit uses an LF353 differential amplifier.

4. The output voltage of this circuit is determined by the formula: $V_E = (V_O - V_F)$

Where V_O = output of DAC
V_F = feedback voltage proportional to actual motor speed
V_E = error voltage



Error detecting

5. V_O is constant because it is determined by the DAC conversion of the DIP switch settings. If the motor ran at a slower speed than the DIP switches were set, the following sequence would occur.

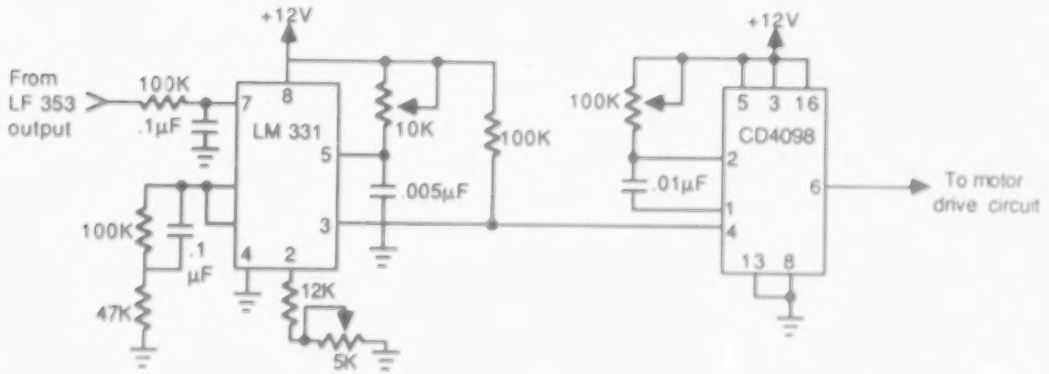
   a. Error voltage would increase because of the difference between V_O and V_F.

   b. This error voltage causes the motor to turn faster.

   c. The faster speed is converted by the speed-to-voltage converter as a higher voltage.

   d. This causes V_F to eventually equal V_O, which causes error voltage to cease and the motor to run at the speed initially set by the DIP switches.

D. Controller circuit

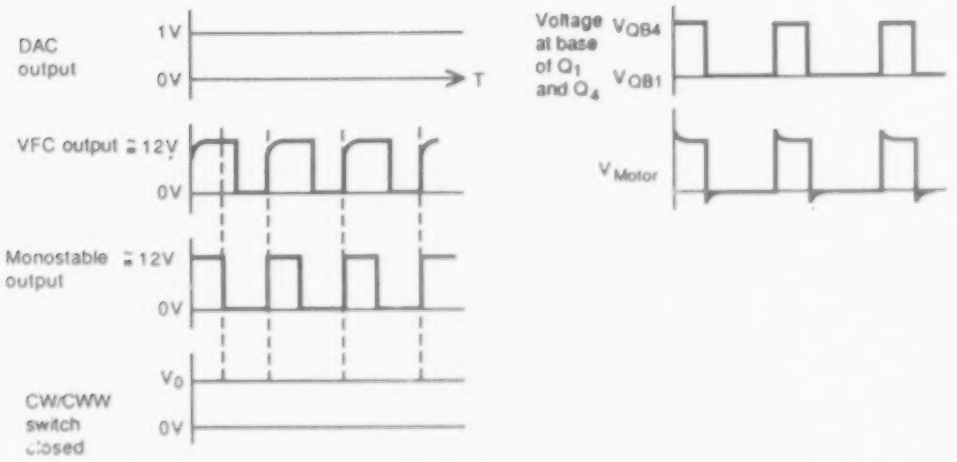


Controller circuit

1. The controller circuit contains a voltage-to-frequency converter (VFC) and a monostable multivibrator. The VFC consists of an LM331 I.C., and the monostable multivibrator circuit consists of a CD4098 I.C., as shown.

2. The purpose of the LM331 is to convert an analog error signal into a pulse waveform. This pulse waveform is applied to the monostable multivibrator.

3. The multivibrator produces a positive pulse (at a width determined by C_1 and R_1) every time a pulse is received from the VFC. The frequency of the pulses from the multivibrator is dependent upon the triggering provided by the VFC. The timing of the system is shown in a figure which follows.



Multivibrator timing

4. Pulse width or duty cycle increases with an increase in error voltage. The greater the pulse width, the more the voltage that is available for the motor during any period of time. This causes the motor to speed up, while a decrease in pulse width causes the motor speed to decrease.

5. R_1's purpose is to adjust the output pulse of the multivibrator so that the correct pulse width is maintained over the range of frequencies (motor speeds) to be controlled. For example, if the range of frequencies are from 20-15,000Hz, the motor should run over this range of frequencies.

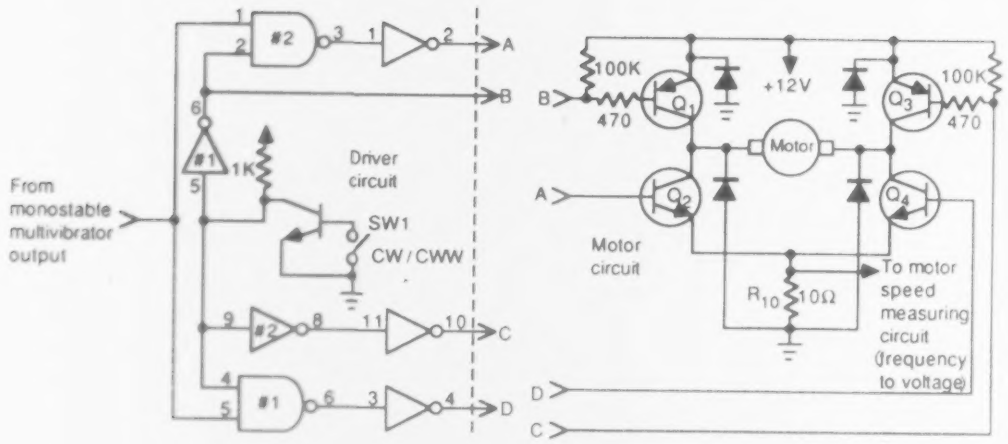
E. Drive and motor circuit

1. This circuit processes output from the controller so that the desired speed is maintained. This circuit also controls the direction the motor turns.

2. When the motor turns clockwise (CW), Q_1 and Q_4 conduct and Q_2 and Q_3 are turned off. When the motor turns counterclockwise (CCW), Q_2 and Q_3 are turned on and Q_1 and Q_4 is turned off.

3. This action is accomplished by the motor control circuit. Output from the monostable multivibrator is applied to logic circuits in the motor control circuits.

4. When SW1 in the motor control circuit is closed, Q_5 conducts, which provides the correct logic to invertor #1 and NAND gate #1 to cause Q_1 and Q_4 to conduct for clockwise operation of the motor. When SW1 is open, Q_5 cuts off and the correct logic is applied to invertor #2 and NAND gate #2 for counterclockwise motor operation.

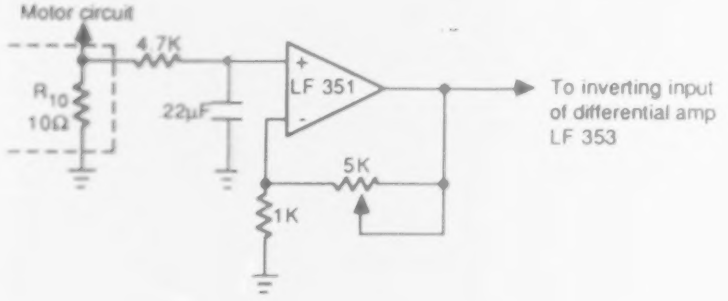


Drive and motor circuit

5. Depending upon SW1's position, when output pulses from the monostable multivibrator enter the control gates, the motor operates either clockwise or counterclockwise. Motor speed is determined by the width of the pulses, which control the conduction time of Q_1 and Q_4 or Q_2 and Q_3.

F. Motor speed measuring circuit

1. The motor measuring circuit converts the speed of the motor into an equivalent voltage. Voltage produced will be different for each speed of the motor.

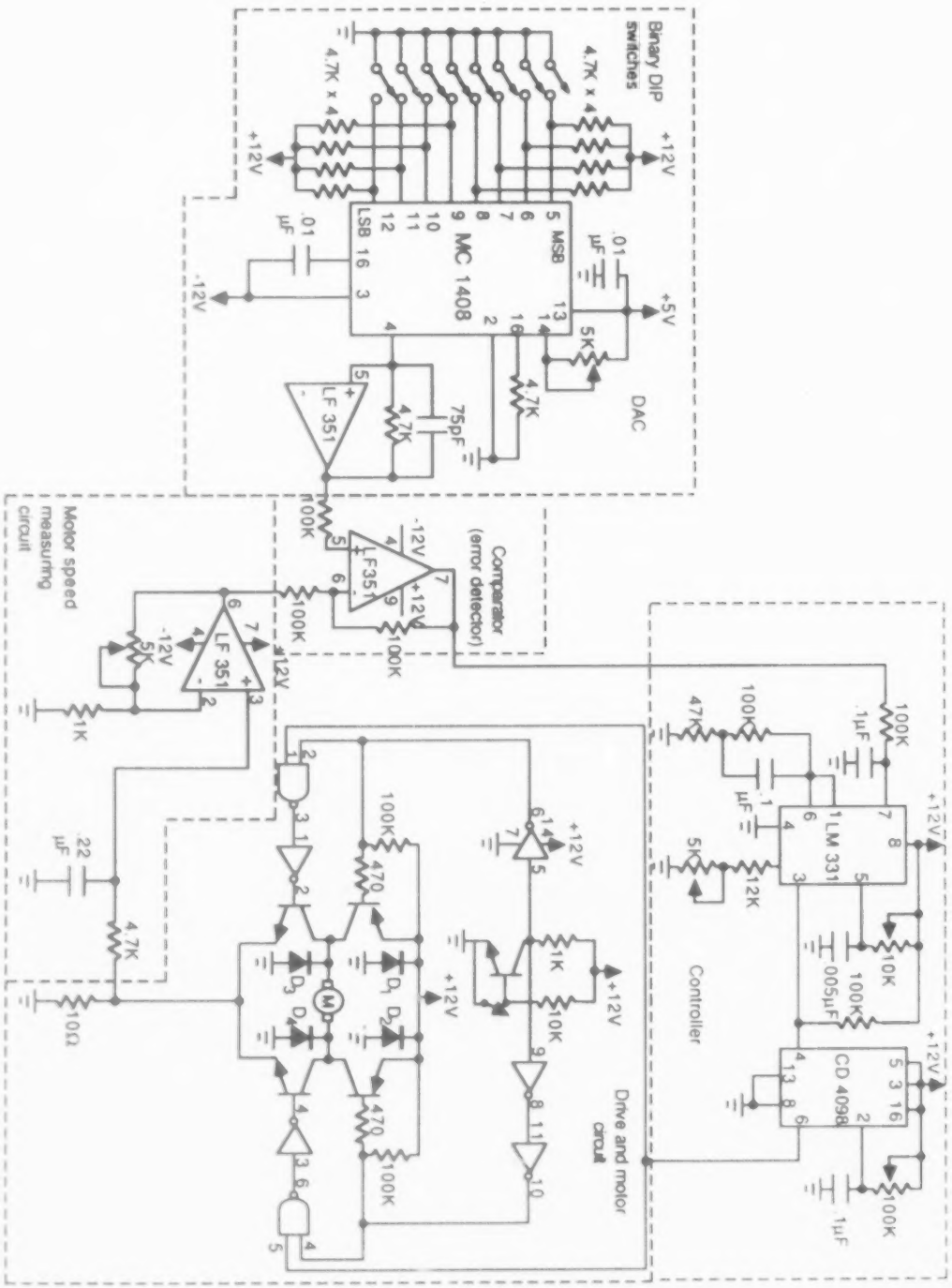


Motor-speed measuring circuit

2. The greater the current that flows through R_{10} and the motor, the faster the motor turns. This produces an increasing voltage drop across R_{10}. The slower the motor runs, the less the current that flows through R_{10}, thus producing less of a voltage drop. As can now be determined, current pulled by the motor is directly proportional to its speed.

3. An LF351 amplifies voltage developed across R_{10} and applies the voltage back to the error detector. This voltage is compared with DAC output voltage, which represents the initial binary switch settings. If these two voltages are different, an error voltage is sent to the controller circuits regulating motor speed.

4. The complete schematic diagram for this circuit is shown above and on the following composite schematic.



MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

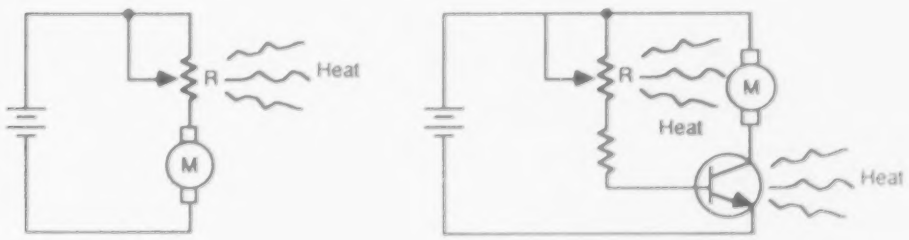
UNIT V: MOTOR SPEED CONTROL

LESSON 2: OPTICAL DC MOTOR SPEED CONTROL

I. Basic considerations

A. When working with motor speed controls, there are cases when it's desirable for the motor speed to be faster or slower. Lesson 1 demonstrated one method. Speed control with continuous DC motors is a science of its own, and there are many ways to accomplish this.

B. One of the simplest ways to control the speed of the DC motor is shown below.



1. This type of operation is, however, very inefficient. The circuit permits the operator to change the speed of the motor by adjusting the variable resistor, thereby changing the voltage which reaches the motor.

2. The larger the ohmic value of the resistor, the less the voltage across the motor. Thus, the motor runs slower. If the variable resistance is reduced, the greater the voltage across the motor and the faster the motor runs. Power dissipated by the resistor is wasted energy.

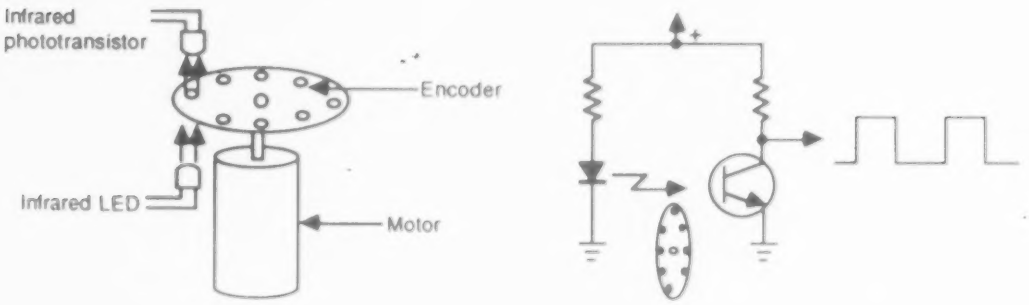
3. Another problem with this arrangement of a resistor in series with the circuit is stall current. A motor normally draws its stall current to begin running from a dead stop. If resistance is placed in series with a motor, it can limit the start-up current or stall current to an extent that the motor cannot begin operating.

II. Optical speed-control operation

A. A closed-loop system is used as an effective speed-control system that can detect whether the motor speed is correct. "Closed loop" means there is some type of mechanism that detects the speed of the motor and sends this information back to the controlling electronics. Changes are corrected, so the motor operates closer to the desired speed.

B. The basic block diagram for this system was explained in lesson 1. This lesson will examine another motor speed-controller system, the optical encoder.

C. The following figure, commonly referred to as an encoder disk, shows an optical encoder disk attached to a DC shaft, an infrared LED and a phototransistor



Encoder disk

1. The disk contains numerous holes along its outside edge. An infrared LED is placed on one side of the disk so that the LED light will shine through the holes when they are aligned.

2. An infrared-sensitive phototransistor is positioned directly on the other sides of the holes. This permits the light from the LED to shine through the encoder disk holes and strike the phototransistor intermittently as the motor shaft turns. The phototransistor outputs this as pulses.

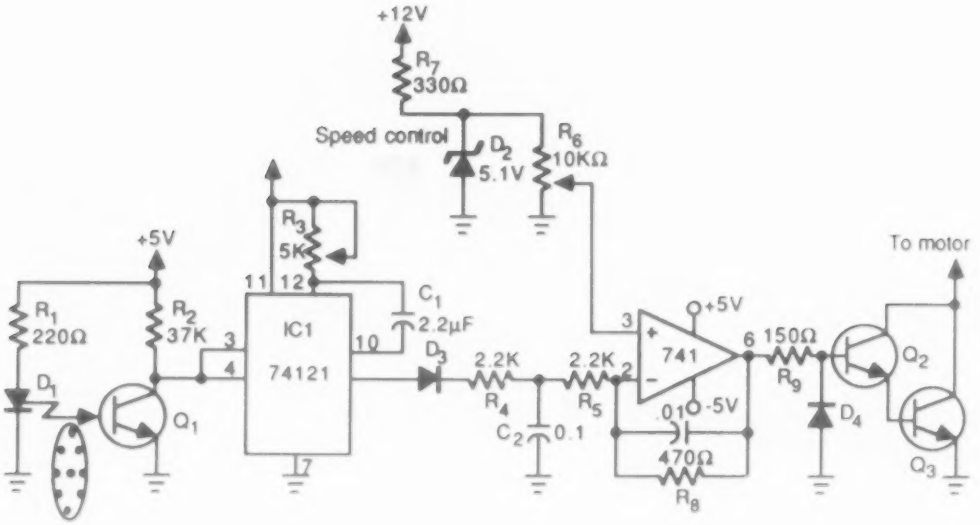
3. The figure at the end of this lesson shows the total system for the optical speed-control circuit.

   a. Pulses from the collector of Q_1 are applied to the one-shot multivibrator, 74121 I.C. The one-shot is a short-duration timer that produces output pulses for a specific duration, no matter how long the input pulse. C_1 and R_3 control the pulse width, and R_1 is variable to control the on-time of the pulses. This control is primarily used to match the output with the motor used.

   b. The one-shot's output is applied to the inverting input of the 741 op amp. R_7 and D1 provides a reference voltage to the op amp's noninverting input. R_6 is adjustable to vary the reference voltage, setting the motor's point of operation.

   c. Op amp output provides a series of pulses directly proportional to reference voltage and one-shot output. When the motor turns too slowly, the op amp lengthens its output pulses, which speeds the motor up. When the motor turns too quickly, the op amp shortens its output pulses, slowing the motor.

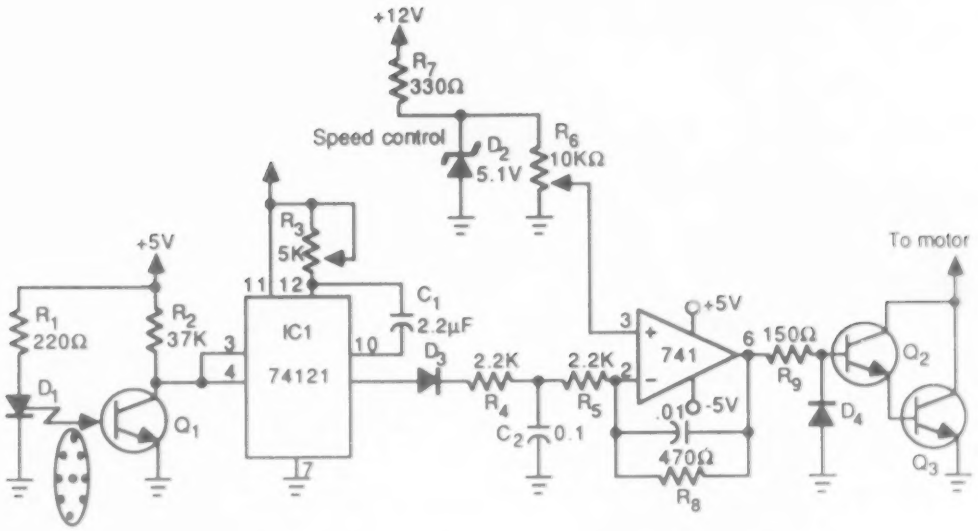
   d. Driving transistors receive pulses from the op amp and are connected directly to the motor.



Optical speed-control circuit

TEST OPTOELECTRONIC SPEED CONTROL

Equipment:



DC power supplies, 5V and 12V
Solderless breadboard
I.C.s: 74121, 741 op amp, 555
2.2μF capacitor
2N3055 transistor (2)
Infrared light-emitting diode
Infrared sensitive photo-transistor
Encoder disk
5K potentiometer
0.1μF capacitor
1N914 diode (2)
5.1V zener diode
6-12V motor
Oscilloscope
Resistors: 220Ω, 330Ω, 2.2KΩ (2), 37KΩ, 470KΩ

Procedure:

		Evaluation 3	2	1	N
1.	Construct the circuit shown above.	—	—	—	—
2.	Apply power to the circuit.	—	—	—	—
	NOTE: Part of the circuit uses 5V and part uses 12V.				
3.	Using an oscilloscope, monitor the signal at pin 3 of the 74121 I.C. and draw two cycles of the signal below; list the frequency.	—	—	—	—

4. **Using the oscilloscope, monitor the signal at pin 2 of the 741 I.C. and draw two cycles of the signal below. List the duty cycle.** — — — —

5. Using the oscilloscope, monitor the signal at the base of Q_2 and draw two cycles of the signal below. — — — —

6. Adjust R_6. Does the motor speed change? Yes / No — — — —

7. Adjust R_3. Does the motor speed change? — — — —

8. Clean up area and return tools and materials. — — — —

Average of above evaluations* — — — —

*This average is the student's final evaluation for competency L8: Describe the operation of motor speed control.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT V: MOTOR SPEED CONTROL

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. When designing a digital DC motor speed-control system, which considerations are important?

a. Cost
b. Constant speed control
c. Speed accuracy
d. All of the above
e. None of the above

____ 2. Which circuits could provide the digital input to a digital speed control?

a. Digital to analog converter
b. DIP switches
c. Comparator
d. Error detector
e. All of the above

____ 3. Which circuit converts digital input signal to voltage used by the comparator?

a. DIP switches
b. DAC
c. Frequency-to-voltage converter
d. Operational amplifier
e. ADC

____ 4. What does the error detector circuit do?

a. Compares digital and analog voltages
b. Changes digital voltage to analog voltage
c. Compares DAC voltage to motor speed voltage
d. Corrects errors from the DAC
e. None of the above

____ 5. Which describes error detector output?

a. Applied to the motor-speed measuring circuit
b. Controls the digital input
c. Controls the comparator output
d. Applied to the controller circuit
e. Results from the controller circuit

____ 6. What does the motor speed measuring circuit change?

a. Frequency to voltage
b. Voltage to frequency
c. Digital to analog voltages
d. Analog to digital code
e. Current to frequency

___ 7. Which results from a large resistor placed in series with a motor?

a. Increased motor speed
b. Increased start-up current
c. Possible limited start-up current
d. Possible overheating of motor
e. Possible increase in stall current

ANSWERS TO UNIT TEST (L8)

1. d
2. b
3. b
4. c
5. d
6. a
7. c

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT VI: ANALOG ELECTRONIC CONTROL DEVICES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to identify the different components that an analog control device can contain and the basic operation of each. This knowledge will be demonstrated by achieving the specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Define terms used with analog control devices.

1.2 Describe the different types of control system components.

1.3 Explain the operation of different types of analog controllers.

1.4 Construct and test analog electronic control devices. (competency L5, JS 1.1)

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT VI: ANALOG ELECTRONIC CONTROL DEVICES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

1. Lesson 1: ANALOG CONTROLS

a. Information outline

b. Job sheet

JS 1.1: Construct and test analog electronic control devices

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Gayakwad, Ramakant, and Leonard Sokoloff. Analog and Digital Control Systems. Englewood Cliffs, NJ: Prentice-Hall, 1988.

2. Harrington, John. Automated Process Control Electronics. Albany, NY: Delmar, 1989.

3. Johnson, Curtis D. Microprocessor Based Process Control. Englewood Cliffs, NJ: Prentice-Hall, 1984.

4. Oleksy, Jerome E. Solid-State Electronics. Indianapolis, IN: Bobbs-Merrill Educational Publishing, 1980.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. There are many circuits that could fit in this unit of instruction which are not specifically identified. Circuits containing UJTs and DIACs can also be used in teaching this unit.

2. Several low-cost component circuits can be used to demonstrate different types of transducers. Examples of these are infrared LEDs and receptors, microphone sound circuits and Hall effect sensor circuits. All of these circuits can be used to control devices.

3. Specific care should be observed when controlling 120V AC lines. Even though these circuits are applicable to today's operations, they can be dangerous to the novice.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT VI: ANALOG ELECTRONIC CONTROL SYSTEMS

LESSON 1: ANALOG CONTROLS

I. Terms and definitions

A. Closed-loop system--system that uses feedback

B. Control system--group of components connected to accomplish a desired output by regulating an energy input

C. Degenerative feedback--when a feedback signal opposes the input signal

D. Feedback--output or part of the output signal that is fed back to be compared to the input signal

E. Open-loop system--system that does not use feedback

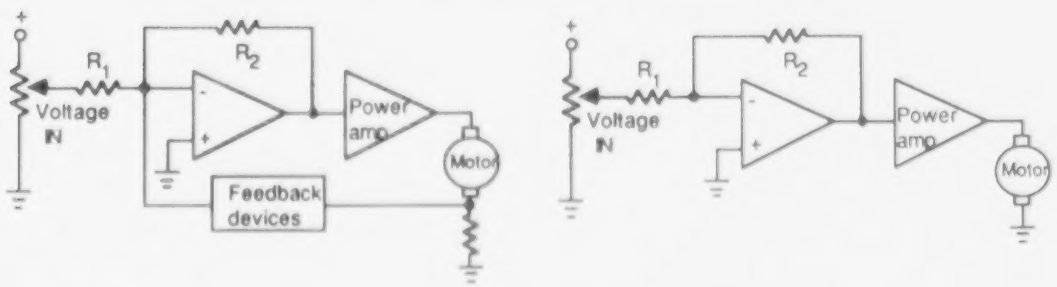
II. Introduction and components

A. Introduction

1. A control system can be defined as one in which some physical quantity is controlled by regulating an energy input. This system can be electrical, pneumatic, hydraulic, mechanical positioning, temperature or a combination of these.

2. Control systems are classified based on feedback use, how the output reaches a desired level, type of components used and application of the system.

3. The simplest types of control systems use either positive (regenerative) or negative (degenerative) feedback systems. Systems can be open-loop or closed-loop controlled. A basic diagram of these systems follows.



Closed- and open-loop control systems

B. Control system components

1. Transducers are an important part of many control systems. A transducer is a device that converts energy from one form to another. For example, to control water temperature in a heater, some type of temperature transducer must be used to indicate to the controller when water needs to be heated.

2. The first stage of measurement is usually a transducer that converts the variable into a form suitable for the controller. In most cases this means a conversion into an electrical variable such as resistance, capacitance or inductance. Some transducers convert directly into voltage.

3. Listed below are some of the most common types of transducers.

   a. Thermistor--A thermistor's operation is based upon the change in its semiconductor resistance with temperature. This device usually has the characteristic of decreased resistance with temperature.

   b. Resistance Temperature Detector (RTD)--This transducer's operation is based on the increase of metal wire resistance with temperature. Normally, it consists of a small coil of platinum or nickel wire protected by a sheath of stainless steel.

   c. Thermocouple--A thermocouple is a temperature transducer that produces voltage directly as a function of temperature. Normally, amplifiers have to be used to amplify the output voltage of a thermocouple into a usable voltage.

   d. Photoconductive cell--This semiconductor device's resistance decreases as light increases.

   e. Displacement transducers--These transducers detect a deviation in position, alignment or location. This deviation becomes an electrical signal with a polarity that indicates the direction of displacement. The magnitude of the electrical signal represents the degree or amount of displacement. Potentiometric, inductive, capacitive and magnetic displacement transducers are available.

   f. Strain gage--Strain gage transducers usually consist of a fine wire attached to a flexible backing. The stress causes the wire to change resistance, which is converted to an analog voltage by electronic circuitry.

4. Many things are analog in nature. Light, heat, sound and motion are examples. Conversions of one of these forms of energy into an electrical form is constantly taking place.

5. For example, a telephone converts sound energy to electrical energy. The person speaking and the telephone transmitter are examples of transducers.

6. An analog control system can contain a combination of amplifiers, transducers and actuators. Analog systems generally use negative feedback systems, which improve system performance.

7. A typical feedback path was shown in the closed-loop illustration earlier. Feedback begins at the system's output. This feedback can be motor speed, temperature, angular position, pressure or flow rate.

8. In the closed-loop illustration, the feedback voltage from the motor represents the actual speed of the motor, and the input voltage represents the desired motor speed. The difference between these two voltages is amplified and becomes the motor input voltage.

9. The motor responds to this incoming voltage by changing its speed accordingly. When there is almost no difference between the input and feedback voltage, the motor will operate at this speed.

III. Analog controllers

A. Transducers used in control systems are available with many different types of analog outputs. These can be current outputs or voltage outputs.

B. Many analog controllers are designed to accept analog input, but their output consists of either on-off control or a set of relay contacts.

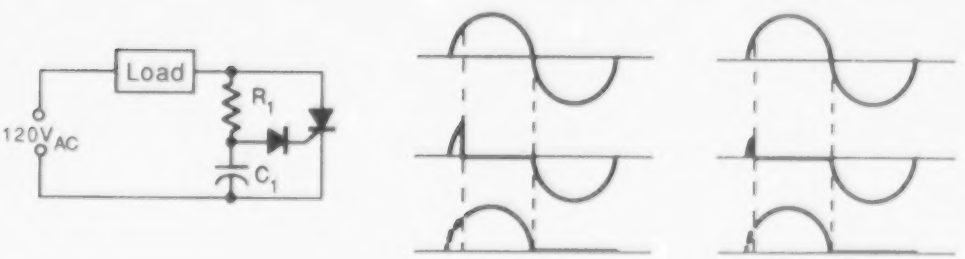
C. On-off control outputs are usually transistor switches. The controller provides the correct bias to drive the transistor into saturation.

D. SCR AC power control

1. The amount of power delivered to a load can be controlled by a silicon controlled rectifier (SCR). This is accomplished by phase control (controlling the time the SCR conducts during the input cycle).

2. An SCR's conduction angle is the amount of time in electrical degrees that the SCR conducts and delivers power to the load.

SCR phase control circuit



LARGE R–The SCR fires late in positive alternation. The load receives power for about half of the alternation.

SMALL R–The SCR fires early in positive alternation. The load receives power for most of the alternation.

3. During the positive alternation of the incoming AC, capacitor C_1 is charged through R_1. When the charge on C_1 is sufficient, the SCR gate is forward biased. Gate current flows, the SCR is switched on and current flows through the load.

4. As the positive alternation nears zero, current in the load decreases below the holding current of the SCR, and the SCR cuts off. This process repeats itself for each alternation.

5. By adjusting R_1, the firing angle of the SCR can be controlled. If the SCR fires late in the positive alternation, current flows in the load for only a brief amount of time. (See "large R" part of SCR phase control circuit illustration.).

6. If R_1 is adjusted so that the SCR fires early in the positive alternation, current can flow in the load for nearly all of half-cycle before the SCR switches off.

7. Diode D1 prevents voltage from the negative alternation from reaching the SCR gate, which could destroy the SCR.

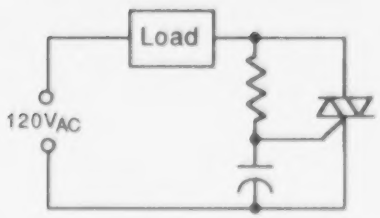
8. This circuit is commonly used as a light dimmer or to control the speed of motors used in small appliances or tools.

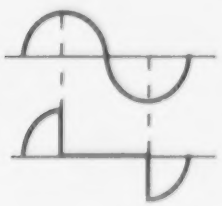
E. TRIAC control

1. The TRIAC provides a simpler means of control for AC circuits. The TRIAC consists of two SCRs mounted in parallel with the anodes of each connected to the cathode of the other.

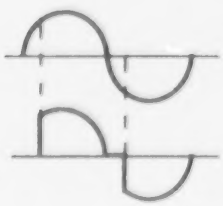
2. The circuit shown in the following figure controls the AC load. The RC network on the gate controls the firing angle of the TRIAC.

TRIAC control





LARGE RC--Fires late in cycle. Low average voltage for load.



SMALL RC--Fires early in cycle. High average voltage for load.

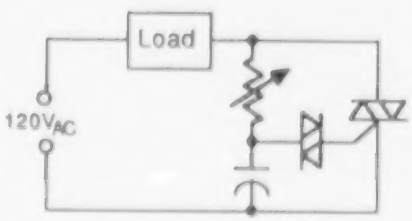
3. The difficulty with this circuit is that the gate of the TRIAC is forward-biased at about 0.7V, which means the control range for a given value of R and C is quite limited.

F. DIAC/TRIAC control

1. The circuit shown below is designed to overcome the difficulty in a TRIAC control system.

2. DIACs only conduct when applied voltage exceeds the breakdown voltage of a DIAC. This ranges from 24 to 35 volts.

3. The DIAC in the figure extends the range of the TRIAC. If the DIAC's breakover voltage is 30V, the capacitor would have to charge to 30V before the TRIAC could be forward-biased.

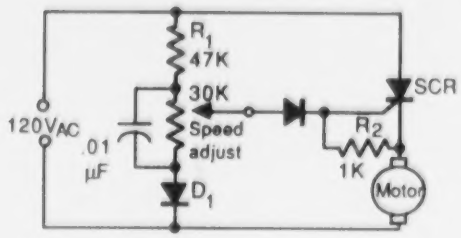


4. The circuit provides a broad range of voltage control and is used extensively in light control systems.

G. Single-phase, half-wave, speed-control system for a DC shunt motor

1. The motor speed is adjusted by R_1, a speed adjust potentiometer. As R_1 is turned up in the direction of the arrow, the motor increases the speed. This occurs because voltage relative to ground permits the gate-to-cathode firing voltage to reach the firing voltage of the SCR earlier in the cycle.

2. As R_1 is turned downward, the gate-to-ground voltage becomes a smaller portion of the line voltage, so it takes longer for the gate-to-cathode voltage to reach the value necessary to fire the SCR.



Half-wave speed control for DC motor

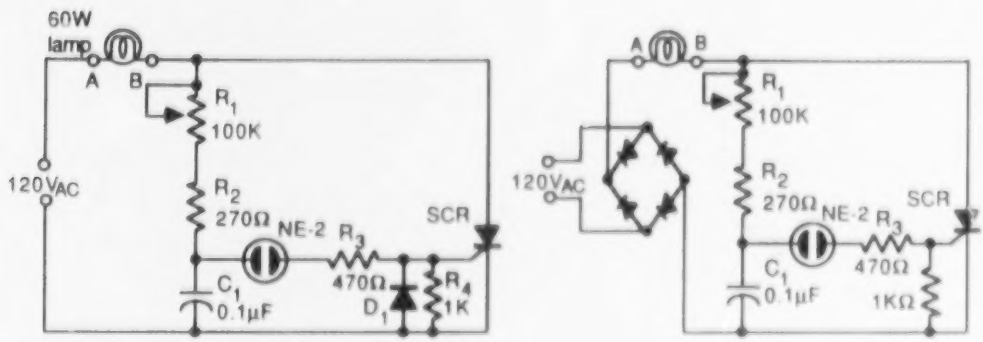
CONSTRUCT AND TEST
ANALOG ELECTRONIC CONTROL DEVICES

Equipment:

SCR (GE C106B1 or equivalent)
60W incandescent lamp
Small motor as might be used in 1/4-inch drill
Silicon diode (4)
0.1μF, 200V capacitor
Neon lamp, NE-2
Resistors: 1KΩ, 470Ω, 270Ω, 100KΩ variable

NOTE: The SCR can be used in phase control circuits to make a variable lamp dimmer. Speed control can also be performed by an SCR circuit. In this job sheet the student will construct and test two lamp-dimmer circuits and one motor control circuit.

Procedure:	Evaluation 3	2	1	N
1. Construct the circuit shown on the left.	—	—	—	—



2. This circuit will give control of the conduction angle over 180° of the input voltage cycle.	—	—	—	—

WARNING: One side of the circuit will be connected to the AC line. Be extremely careful in handling the control to make any adjustments. Don't make any voltage or waveform measurements without the instructor's approval.

3. Apply 120V AC to the circuit and vary R_1 to dim and brighten the lamp. Comment on your observations.	—	—	—	—

4. Using any small universal motor (mixer, small drill, sewing machine) remove the lamp from the circuit and connect the motor to points A and B. — — — —

5. Apply power to the circuit and vary its speed with R_1. Comment on the results. — — — —

6. After the half-wave control circuit has been tested, construct the right-hand circuit shown earlier. Notice that bridge rectifier will cause both alternations to be positive, thus giving control over 360° of the cycle. Also notice that the diode from gate to cathode is needed in this circuit. — — — —

7. Apply power to the circuit and vary R_1 to change the lamp's brightness. Compare the operation of this circuit to the circuit in the left-hand figure and comment below on any differences. — — — —

8. Remove the lamp from the circuit and connect the motor across points A and B. Vary the speed with R_1. Compare this circuit with the circuit in the first figure and note any differences. — — — —

Average of above evaluations* — — — —

*This average is the student's final evaluation for competency L5: Test and repair analog electronic control devices.

NOTE: Due to inexpensive replacement costs, the repair of an analog electronic control device is uncommon since it's more practical to replace it than repair it.

MODULE: ELECTROMECHANICAL DEVICES AND CONTROLLERS

UNIT VI: ANALOG ELECTRONIC CONTROL DEVICES

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which term refers to an analog electronic control system that uses feedback as a means of control?

a. Closed loop
b. Open loop
c. Pneumatic
d. Degenerative
e. None of the above

____ 2. Which describes a degenerative feedback system?

a. Feedback signal that aids the input signal
b. Feedback signal that opposes the input signal
c. Not used in analog control systems
d. Only used in digital circuits
e. None of the above

____ 3. What is a regenerative feedback system?

a. Feedback signal that aids the input signal
b. Feedback signal that opposes the input signal
c. Not used in analog control systems
d. Only used in digital circuits
e. None of the above

____ 4. How is positive feedback sometimes referred to?

a. Digital feedback
b. Degenerative feedback
c. Regenerative feedback
d. Analog feedback
e. None of the above

____ 5. How could thermistors, thermocouples, photoconductive cells and strain gages be classified?

a. Heat sensors
b. Light sensors
c. Displacement devices
d. Transducers
e. Transistors

____ 6. Which is a temperature transducer that produces voltage directly as a function of temperature?

a. Photoconductive cell
b. Thermistor
c. Thermocouple
d. Displacement transducer
e. Resistance temperature detector

___ 7. What kind of transducer's resistance increases as light decreases?

a. Thermocouple
b. Photoconductive cell
c. Strain gage
d. Resistance temperature detector
e. Thermister

___ 8. In nature, which best describes light, heat, sound and motion?

a. Analog
b. Digital
c. Resistive
d. Capacitive
e. None of the above

___ 9. Which describes transducers that are used in control systems?

a. Current outputs only
b. Voltage outputs only
c. Resistance outputs only
d. Current or voltage outputs
e. Digital outputs

___ 10. What do control outputs of analog controllers usually use?

a. AC voltages
b. On-off control devices
c. Resistors
d. Transistors
e. Both b and d

ANSWERS TO UNIT TEST (L5)

1. a
2. b
3. a
4. c
5. d
6. c
7. b
8. a
9. d
10. e